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CEX-58.4.5

CIVIL EFFECTS STUDY

AERORADIOACTIVITY SURVEY AND
RELATED SURFACE GEOLOGY OF PARTS
OF THE SAN FRANCISCO REGION,
CALIFORNIA (ARMS-I)

Kenneth G. Books

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AERORADIOACTIVITY SURVEY AND RELATED SURFACE GEOLOGY OF PARTS OF THE SAN FRANCISCO REGION, CALIFORNIA (ARMS-I)

By

Kenneth G. Books

Approved by: Director
U. S. Geological Survey

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U. S. Geological Survey
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Division of Biology and Medicine, USAEC
September 1963

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ABSTRACT

A recent aeroradioactivity survey in the San Francisco region, Calif., shows a moderate range of 0 to 1000 counts per second in the levels of natural radioactivity. The lower levels can be related to unconsolidated sediments with a high water content and the higher levels can be related to igneous rocks or alluvium and soils derived from igneous rocks.

The survey is approximately 14,000 square miles in area and was made by the U. S. Geological Survey on behalf of the Division of Biology and Medicine, U. S. Atomic Energy Commission. Continuous radioactivity profiles were obtained with scintillation counting equipment at approximately 500 ft above the ground on parallel northeast-southwest flight lines spaced 1 mile apart. A map of aeroradioactivity levels was prepared from the profiles.

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PLATE

1.	Natural Gamma Aeroradioactivity Map of Parts of the San Francisco Region, California	in pocket
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AERORADIOACTIVITY SURVEY AND RELATED SURFACE GEOLOGY OF PARTS OF THE SAN FRANCISCO REGION, CALIFORNIA (ARMS-I)

1. INTRODUCTION

1.1 Location of Area

An aeroradioactivity survey in the San Francisco area, Calif., was made by the U. S. Geological Survey on behalf of the Division of Biology and Medicine, U. S. Atomic Energy Commission during October and November, 1958, and April and May, 1959, as a part of the Aerial Radiological Measurement Surveys (ARMS-I) program.

The total area of survey is approximately 14,000 square miles. The major part extends from San Francisco on the west to Sacramento on the east and from Colusa on the north to the Merced River on the south (Fig. 1). Two areas are separated from the main part of the survey. The first is northwest of San Francisco and lies between Santa Rosa and the ocean. The second is southeast of San Francisco near Watsonville. Single line traverses were made along roads north and west of San Pablo Bay, west of San Francisco Bay, and in the Santa Clara Valley (Pl. 1). Rough topography precluded flying all 14,000 square miles.

1.2 Purpose of Survey

The survey is part of a nationwide program to obtain data on the existing gamma radioactivity for areas in, and adjacent to, nuclear facilities. These data provide information that can be used to detect any future variations in radioactivity that might result from nuclear testing, reactor or other Atomic Energy Commission operations, or radioactivity accidents.

Nuclear facilities within the area of the survey include: (1) Naval Radiological Defense Laboratory, U. S. Navy, Mare Island; (2) General Electric Company facility, Pleasanton; (3) General Electric Company facility, San Jose; (4) Lawrence Radiation Laboratory, Berkeley; (5) and Lawrence Radiation Laboratory, Livermore. The detailed survey of the Livermore facilities is discussed later in this report (Sec. 4).

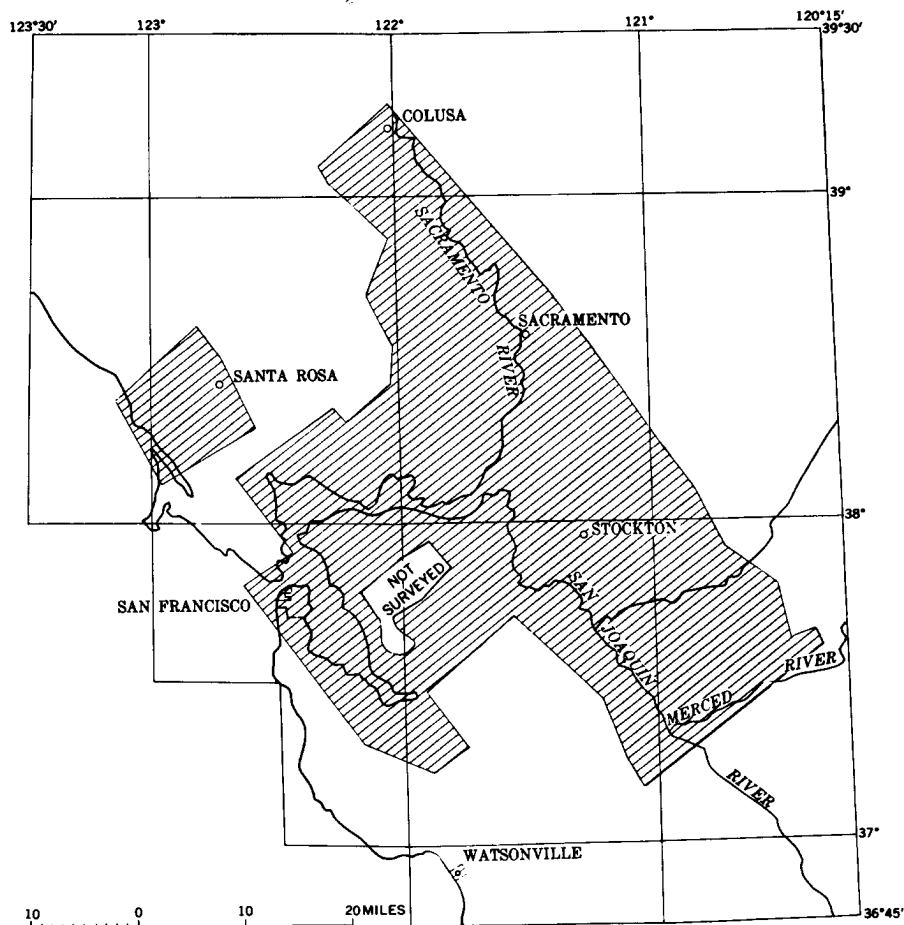


Fig. 1—Areas surveyed in the San Francisco region, California.

1.3 Airborne Survey Procedure

The survey was made with scintillation detection equipment installed in a twin-engine aircraft. Parallel flight lines were spaced 1 mile apart and flown in northeast-southwest directions to cross the general geologic trend in the area. The aircraft maintained an approximate altitude of 500 ft above the ground at an average air speed of 150 mph; topographic maps were used for pilot guidance. The flight path of the aircraft was recorded by a gyrostabilized continuous-strip-film camera, and the distance of the aircraft from the ground was measured by a continuously recording radar altimeter. Fiducial markings which provide a common reference for the radioactivity and altimeter data and the camera film, were made with an electromechanical edge-mark system operated by the flight observer when the aircraft passed over recognizable features on the ground. A more detailed explanation of airborne survey procedure was published by Keller and others¹.

1.4 Compilation of Aeroradioactivity Data

Flight-line locations from strip-film obtained during the survey were plotted on compilation base maps (scale: 1 in. equals 1 mile).

The altitude-compensated radioactivity profiles from adjacent flight lines were examined, and changes or breaks in the level of the radioactivity record were selected and their location on each flight line plotted on the base map. The changes were correlated from line to line and are indicated on the map (Pl. 1) by solid or dashed lines. The difference between the lines is a matter of degree; the solid lines denote distinct major changes in the level of radioactivity and the dashed lines denote relatively less distinct, generally transitional changes. Areas between the lines of change were assigned general ranges of radioactivity levels by scanning the records obtained over the specific areas. The lines of change and the radioactivity levels were plotted along flight lines on transparent overlays of the compilation base maps. The overlays were reduced to a scale of 1 in. equals 4 miles (1:250,000) and the data were plotted on the final base map. The final map (Pl. 1)² was derived from the Army Map Service, 1:250,000 topographic map series, Chico, Sacramento, San Francisco, San Jose, Santa Rosa, and Ukiah sheets.

1.5 Scintillation Detection Equipment

The aeroradioactivity detection equipment used by the Geological Survey was designed by the Health Physics Division of the Oak Ridge National Laboratory and is described in detail by Davis and Reinhardt³. They describe the sensitivity of the equipment in several ways, one being (Ref. 3, p. 717) "...the count rate for a dose rate of one microrentgen per hour due to radium gamma rays is 225 cps (counts per second)." For simulated plane sources Davis and Reinhardt⁴ state (p. 239), "The count rates at 500 ft equivalent to a ground reading of 1 μ r/hr [microrentgen per hour] for Cs¹³⁷ and Co⁶⁰ plane sources are 25 and 18 counts/sec, respectively." Kermit H. Larsen of the University of California, Los Angeles, determined in 1958⁵ that a count rate of about 77,000 cps would be recorded by the Geological Survey equipment flying at 500 ft above a virtually infinite area of fallout that produced a gamma-ray flux of 1 mr/hr (milliroentgen per hour) at 3 ft above the ground.

A diagram of the equipment is shown in Figure 2. The detecting element consists of six thallium-activated sodium iodide crystals, 4 in. in diameter and 2 in. thick, and six photomultiplier tubes connected in parallel. The signal from the detecting element is amplified and fed through a pulse-height discriminator which is usually set to accept only pulses originating from gamma radiation with incident energies greater than 50 kev. The signal is then fed to two rate meters. One rate meter feeds a circuit that records total radioactivity on a graphic milliammeter. The signal from the other rate meter is recorded by a circuit that includes a variable resistance which is controlled by the radar altimeter servomechanism, thereby approximately compensating the data for deviations from the nominal 500-ft surveying altitude.

The crystals are shielded on the sides by $\frac{1}{2}$ in. of lead, which nullifies any influence of the radium-dial instruments in the aircraft. The effective area of response at an elevation of 500 ft is approximately 1000 ft in diameter and the radiation recorded is an average of the radiation received from within the area. Theoretical

content and type of the radioactive minerals in the parent rock and by changes due to geologic and soil-forming processes. An important consideration in studying the radioactivity of a soil is whether it is a residual soil derived from the rock beneath it or a transported soil that may be derived from rocks that are entirely different from those on which the soil rests. Although complete studies of the distribution of natural radionuclides in the various soils and rocks of the surface layer have not been made, information concerning individual components is available. Radioactive heavy minerals, such as monazite, a rare-earth phosphate containing as much as 30 percent thorium, and zircon, a zirconium silicate containing as much as 1 percent uranium, are present in small quantities in many types of rocks and soils. Potassium, having a relative abundance¹⁰ of 0.012 percent K^{40} , is also a common component of rocks and soils. The concentration of these or any other radioactive minerals at the surface of a residual soil may be greater or less than their concentration in the parent rock, depending on the interplay of the various soil-forming processes.

2. GENERAL SURFACE GEOLOGY

The composite surface geologic maps in this report (Figs. 3, 4, and 5) are, where possible, generalizations of the geologic maps of California^{11,12}, but they may have other sources¹³. Each map shows generalized geologic boundaries as well as radioactivity boundaries.

The lists of map symbols that accompany the surface geologic and aeroradioactivity maps consist of 14 divisions that are a consolidation of many more geologic units. The divisions are grouped chronologically and range in age from Mesozoic to Recent. They are further grouped on the basis of lithology and, where possible, into marine and nonmarine subdivisions. The marine and nonmarine subdivisions are for simplification and do not imply that either marine or nonmarine sedimentary units have a greater radioactivity.

Rocks of Mesozoic age are widely distributed throughout the survey area and because of their heterogeneity they form some of the least satisfactory of the groupings. Sedimentary rocks are predominantly marine and except for the Franciscan Formation and the Knoxville Formation are grouped as such. Igneous rocks include granitic, mafic and ultramafic intrusive and volcanic types. Some of the volcanic rocks were metamorphosed.

Rocks of Tertiary age include both marine and nonmarine sedimentary rocks and volcanic rocks. Nonmarine sedimentary rocks of Quaternary age form the largest single division and cover most of the area surveyed.

3. GENERAL DISTRIBUTION OF AERORADIOACTIVITY

Although in places there is a positive correlation of the surficial rock and soil and the general intensity of radioactivity, in many places they are related only in a discontinuous way or not at all.

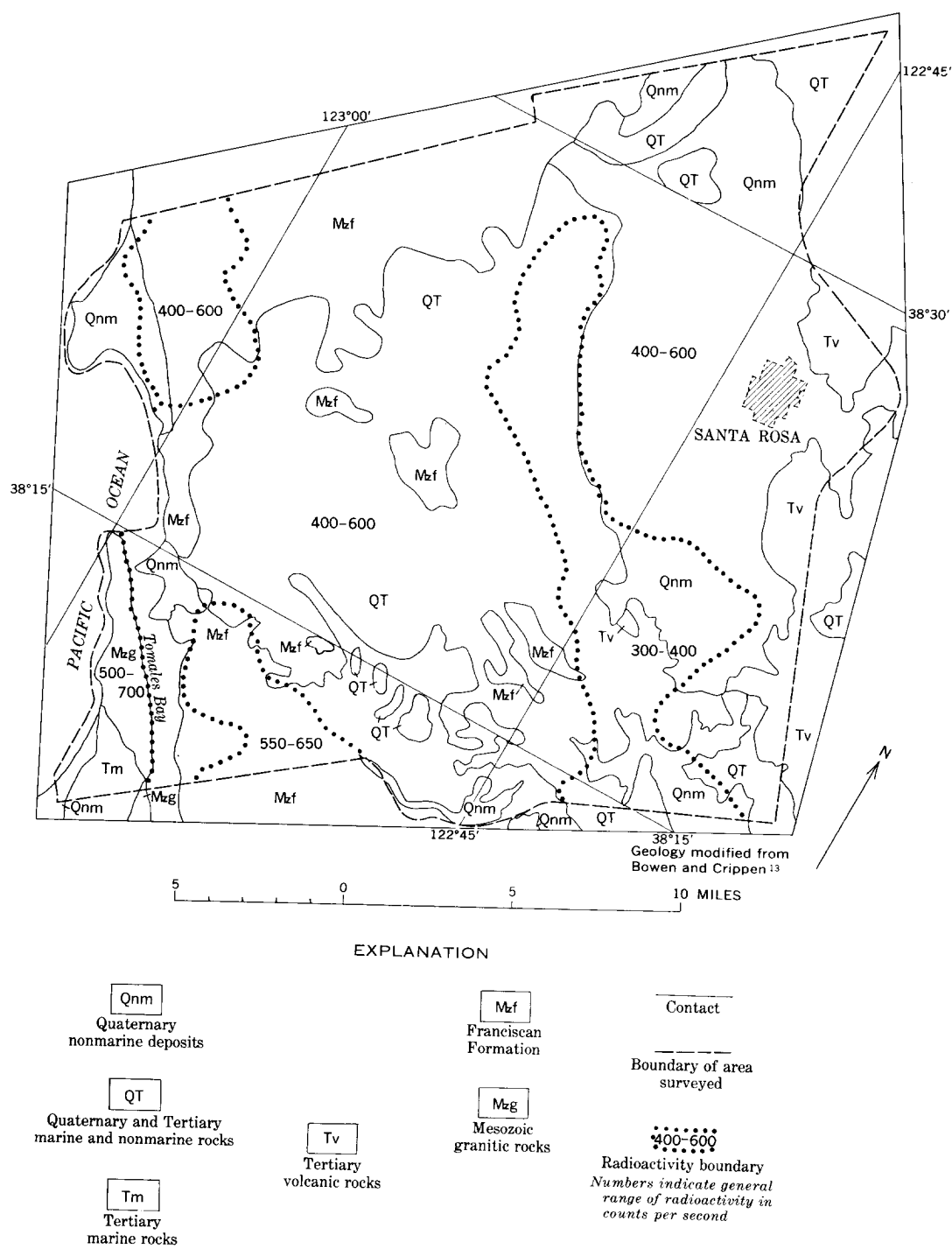


Fig. 3—Generalized surface geology and aeroradioactivity map of the Santa Rosa area, California.

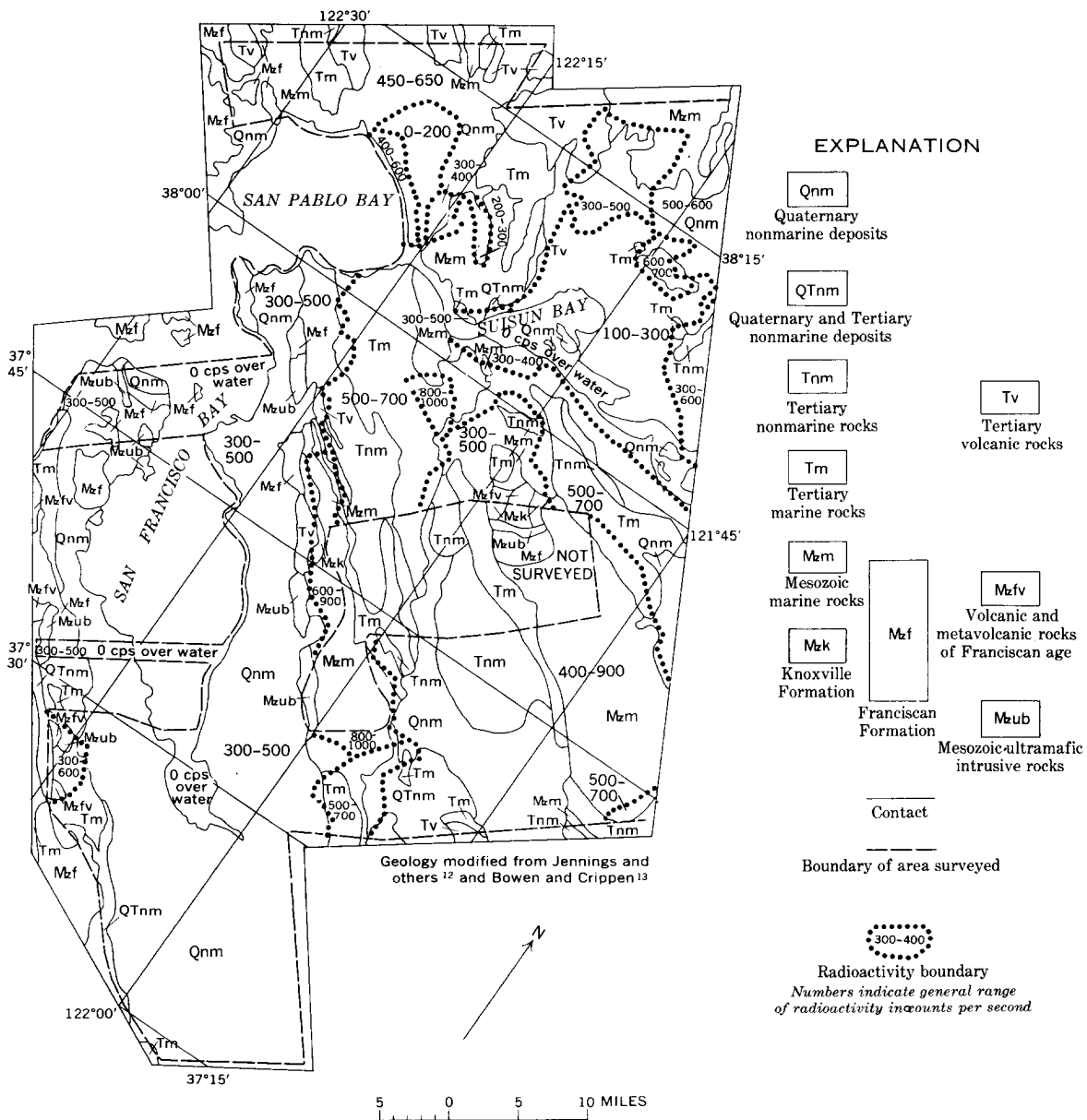


Fig. 4—Generalized surface geology and aeroradioactivity map of the San Francisco Bay–San Pablo Bay–Suisun Bay areas, California.

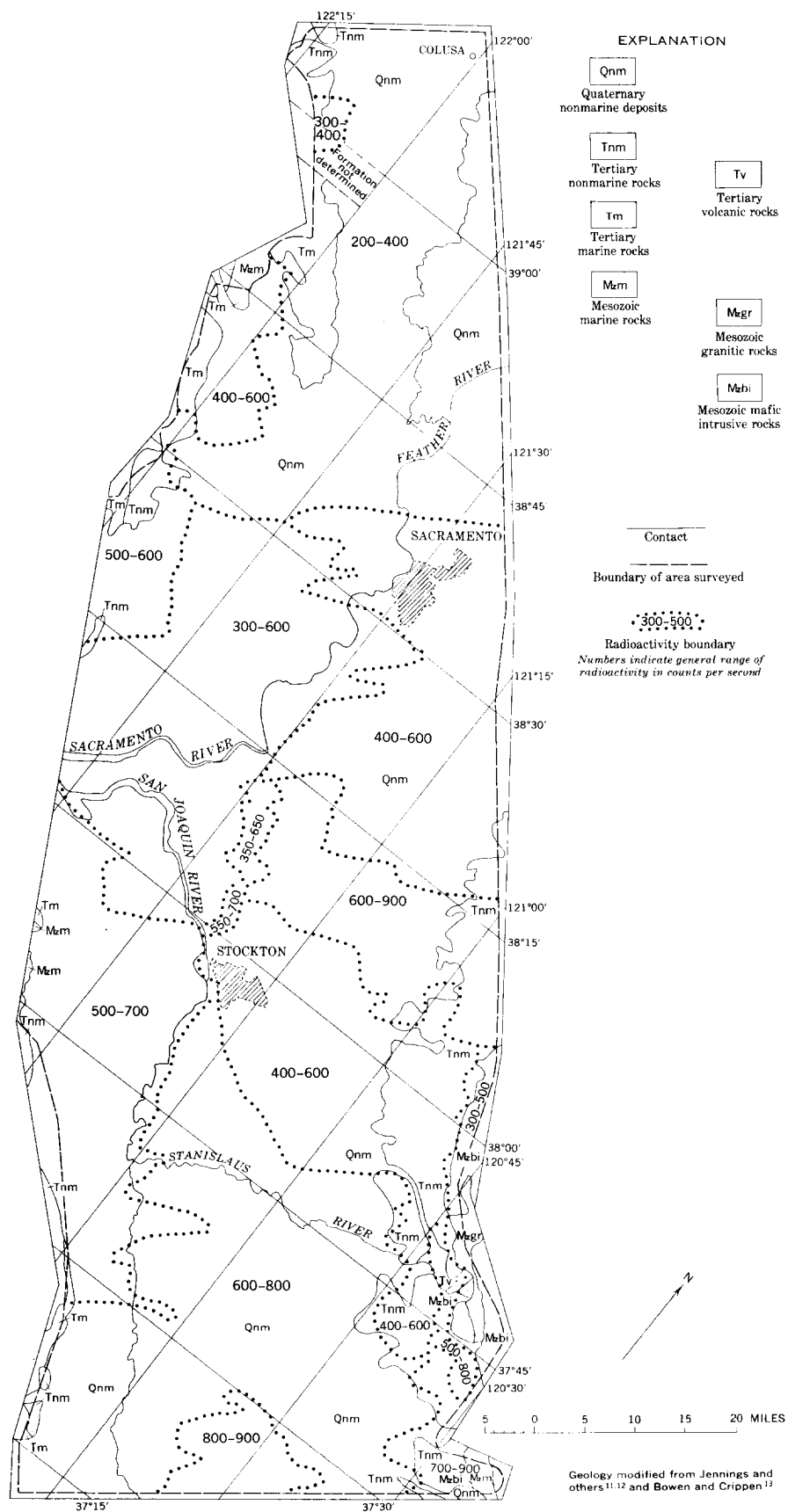


Fig. 5—Generalized surface geology and aeroradioactivity map of part of the Great Valley area, California.

The highest levels of radioactivity are usually associated with igneous rocks or soils derived from igneous rocks. The lowest levels are associated with regions near bays or marshy areas where the high concentration of water in the ground produces a masking effect. Intermediate levels are found over areas underlain by sedimentary rocks or alluvium.

The survey has been subdivided into four areas for discussion of the aeroradioactivity. The first three lie in the Coast Range province, the fourth lies in the Great Valley province. They are (1) the Santa Rosa area, (2) the San Francisco Bay-San Pablo Bay-Suisun Bay area containing the lowlands around the bays, (3) the area of higher elevations east and northeast of San Francisco Bay, and (4) the Great Valley area from Colusa on the north to the Merced River on the south.

3.1 Distribution of Radioactivity Relative to Surface Geology in the Santa Rosa Area

Radioactivity levels in the Santa Rosa area are moderate and range from 300 to 700 cps (Fig. 3). Over nonmarine formations of Quaternary age and marine and nonmarine formations of Tertiary age the radioactivity level is 300 to 600 cps, but it is as high as 700 cps over the quartz diorite of Late Cretaceous age west of Tomales Bay.

Radioactivity levels increase toward the east near the volcanic rocks of Tertiary age located just outside the project area, and are definitely higher (550 to 650 cps) over the Franciscan Formation east of Tomales Bay.

3.2 Distribution of Radioactivity Relative to Surface Geology in the San Francisco Bay-San Pablo Bay-Suisun Bay Area

Radioactivity levels in the immediate vicinity of San Francisco Bay range from 300 to 500 cps (Fig. 4). Southwest of the bay there is a small area where the level is higher (300 to 600 cps). This level is associated with Franciscan volcanic rocks and ultramafic intrusives of Mesozoic age.

In the San Pablo-Suisun Bay area the radioactivity levels are more varied. Around San Pablo Bay they range from 0 to 200 cps on the east to 500 to 700 cps on the south. Around Suisun Bay they range from 100 to 300 cps on the north to 500 to 700 cps on the south. The lower levels near both bays are probably due to the masking effect of water.

3.3 Distribution of Radioactivity Relative to Surface Geology in the Area of Higher Elevations East and Northeast of San Francisco Bay

In the area of higher elevation east and northeast of San Francisco Bay the rock types are more varied, as are the radioactivity levels. These range from 300 to 1000 cps. The higher levels are

generally associated with marine sandstone, shale, and conglomerate of Cretaceous, Paleocene, and Eocene age. Specifically, on the geologic map of California¹² those units having a higher radioactivity are the Markley Formation, the Martinez Formation of Lawson, the "Chico" Formation, and some undivided rocks of Cretaceous age.

3.4 Distribution of Radioactivity Relative to Surface Geology in the Great Valley Area

Within the area surveyed in the Great Valley the radioactivity levels range from 200 to 900 cps (Fig. 5). There is a general southward increase from 200 to 600 cps in the north to 400 to 900 cps in the south.

Because surficial deposits over most of the area consist of alluvium, stream channel deposits, fan deposits, and basin deposits, many of which probably have been intermixed and are not mineralogically representative of any one particular rock type, there are no really significant relationships between radioactivity levels and surface geology.

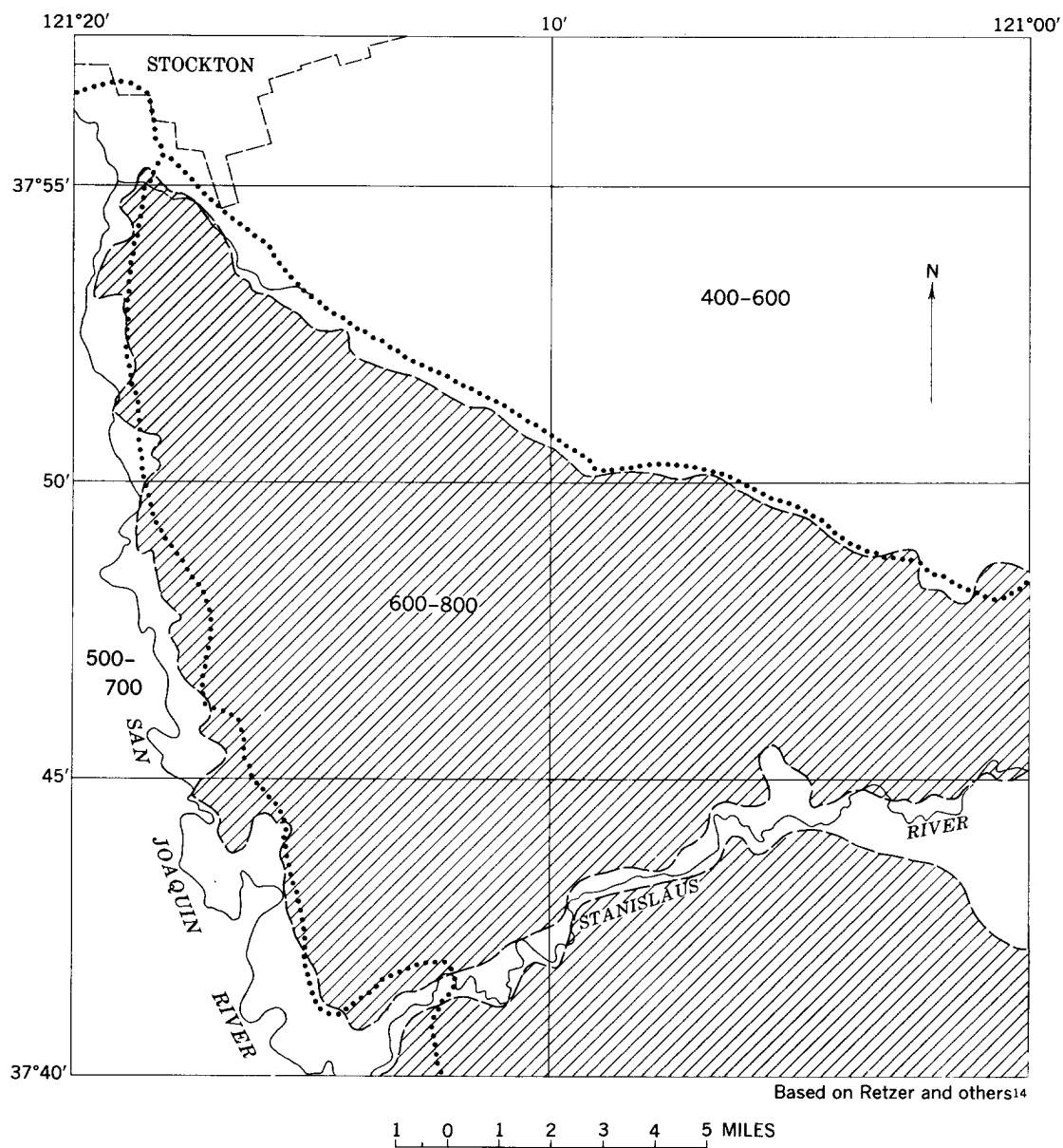
Where surficial deposits have not been intermixed, or where the soils have been derived primarily from one rock type, the possibility of correlation between radioactivity and surface deposits is enhanced. One such area where the radioactivity level is greater than surrounding levels and where the soils have granitic rocks as the parent rock is shown in Figure 6. This, however, is discontinuous and correlation does not extend beyond the Stanislaus River on the south.

4. DETAILED SURVEY OF THE LIVERMORE NUCLEAR FACILITY


The Lawrence Radiation Laboratory, Livermore, is located at the abandoned airfield about 2 miles east of the town of Livermore, Calif. (Fig. 7).

In addition to the northeast-southwest flight lines across the area, seven north-south traverses at $\frac{1}{4}$ mile spacing were flown over the facility. Natural background radioactivity over surficial deposits in the area may vary from 300 to 550 cps.

Six anomalies varying in intensity from just over background to almost 9 times background were measured over the facility area. All anomalies result from normal atomic energy operations at the nuclear facility and from the fact that the Geological Survey equipment (instrumentation) is extremely sensitive to small changes in radioactivity levels. Information on radioactivity levels in the environs and outside the plant boundaries is reported from selected Atomic Energy Commission and contractor installations. This information is reviewed and abstracted for inclusion in the U. S. Public Health Service series of reports entitled "Radiological Health Data". They are issued monthly and can be purchased from the Superintendent of Documents, U. S. Government Printing Office, Washington, D. C. 20402.



EXPLANATION


Area of soils derived from
granitic rocks

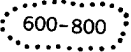
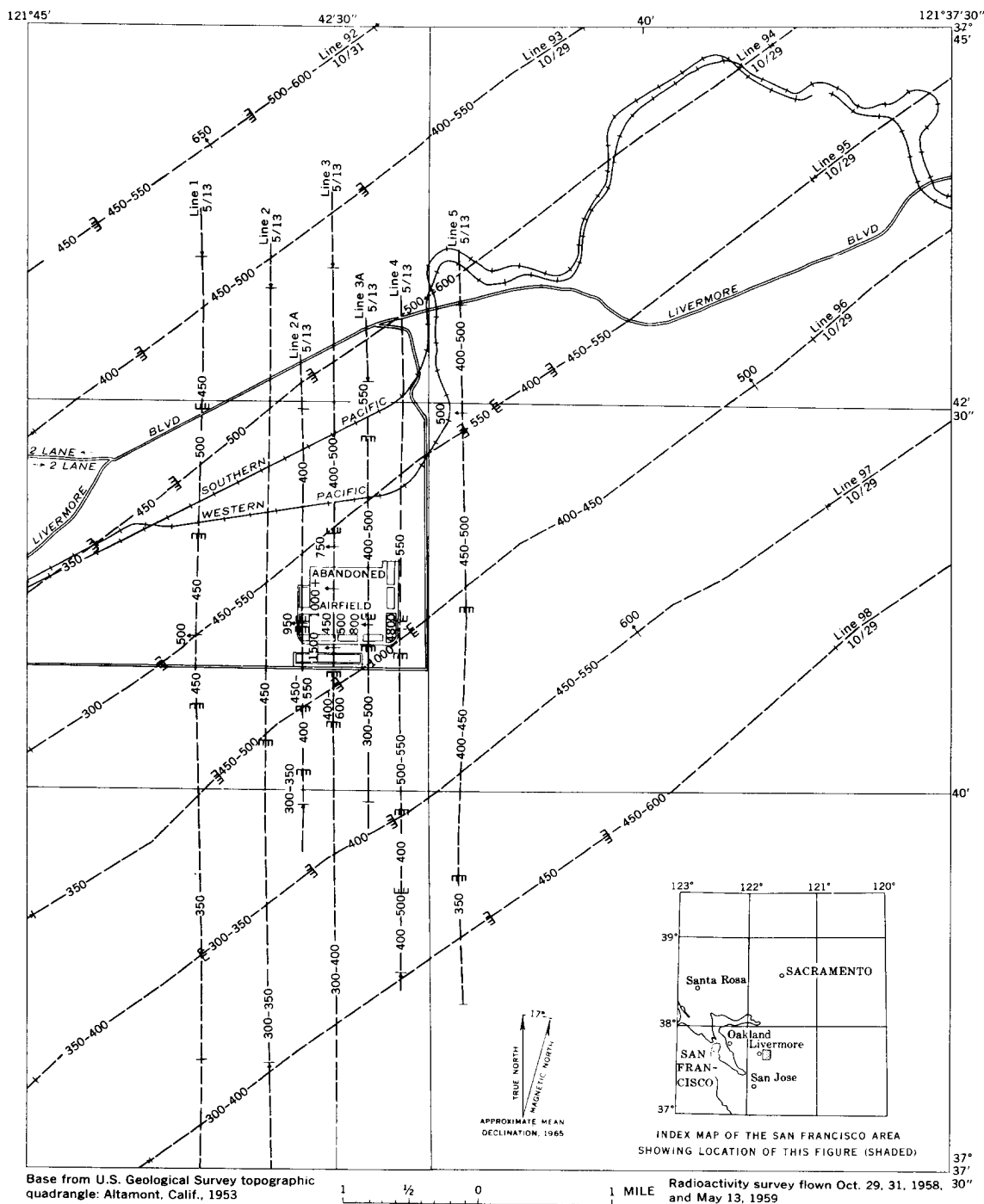

Radioactivity boundary
*Numbers indicate general range of
radioactivity levels in counts per second*

Fig. 6—Generalized soils and aeroradioactivity map of an area south and east of Stockton, California.



EXPLANATION

— 500 — 800 — 1000 — 800 — 400-500 — 800 —
300

Radioactivity levels and points of change
in level along flight line

Arrows between hatchures that also enclose
radioactivity levels indicate position of
narrow high or low. Arrows alone
between hatchures indicate position of
broad high or low

— Line 2 —
5/13

Flight line

Showing end of measured interval, direction
of flight, number and date of flight

Fig. 7—Aeroradioactivity survey, Lawrence Radiation Laboratory, Livermore, California.

5. SUMMARY

The aerial radioactivity measurements in the San Francisco-Great Valley region were collected largely over nonresidual alluvium or unconsolidated sediments with a high water content and consequently do not correlate well with local bedrock geology. The intensity of radioactivity is moderate and in general is highest over igneous rocks or soils derived from igneous rocks. It is lowest in marshy areas owing to the masking effect of water and has the greatest variation in the Coast Range areas where rocks are lithologically more complex.

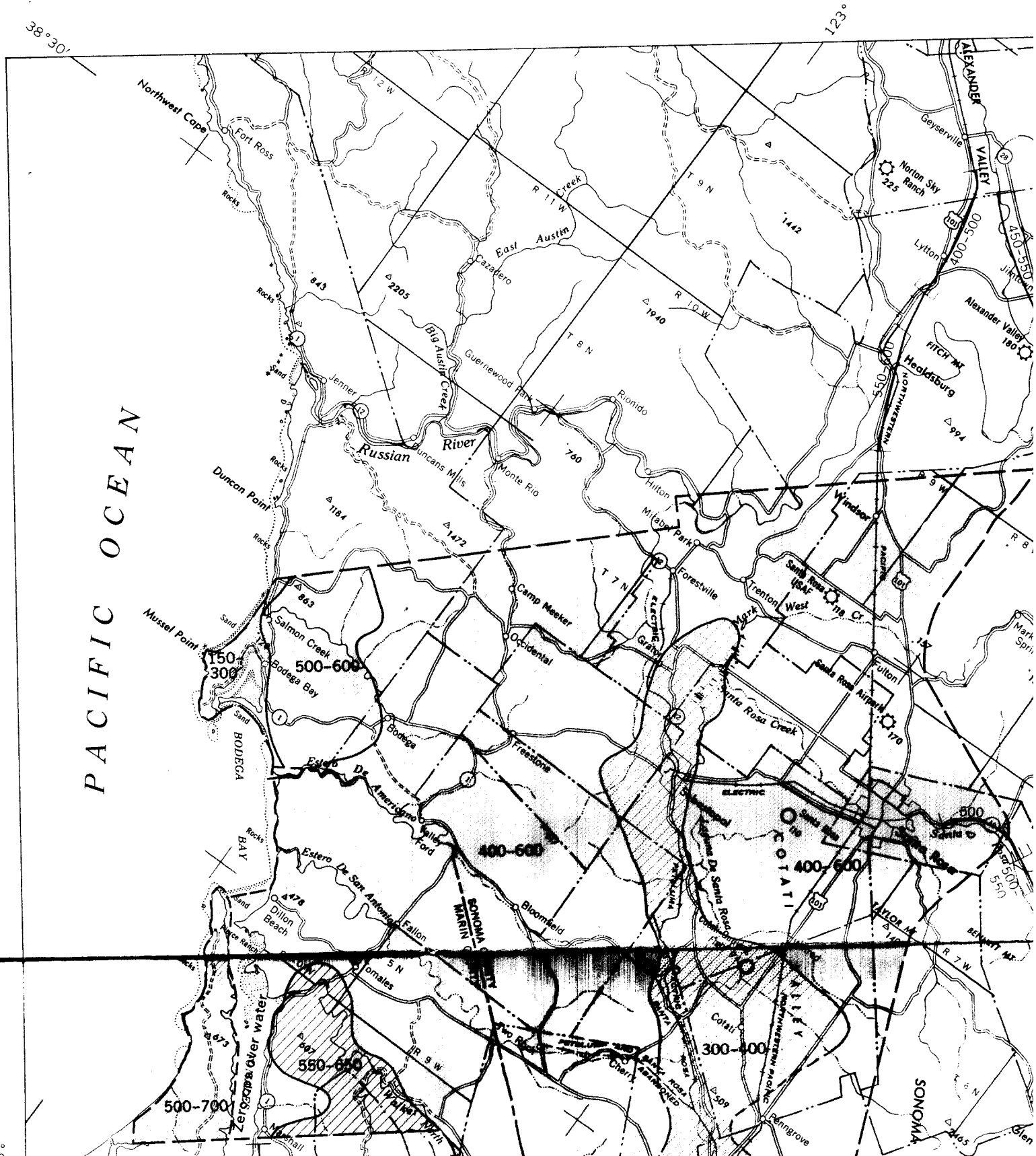
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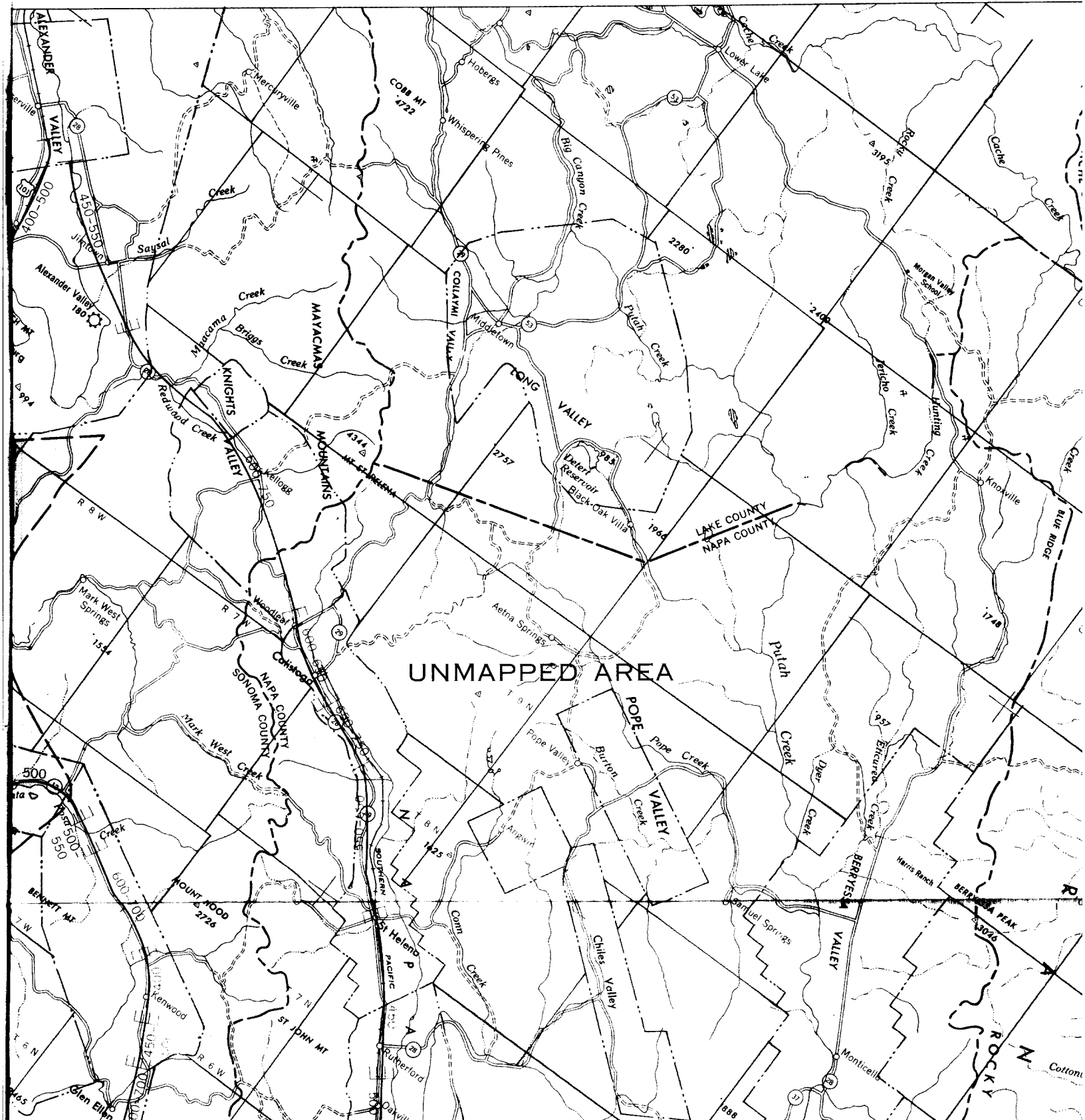
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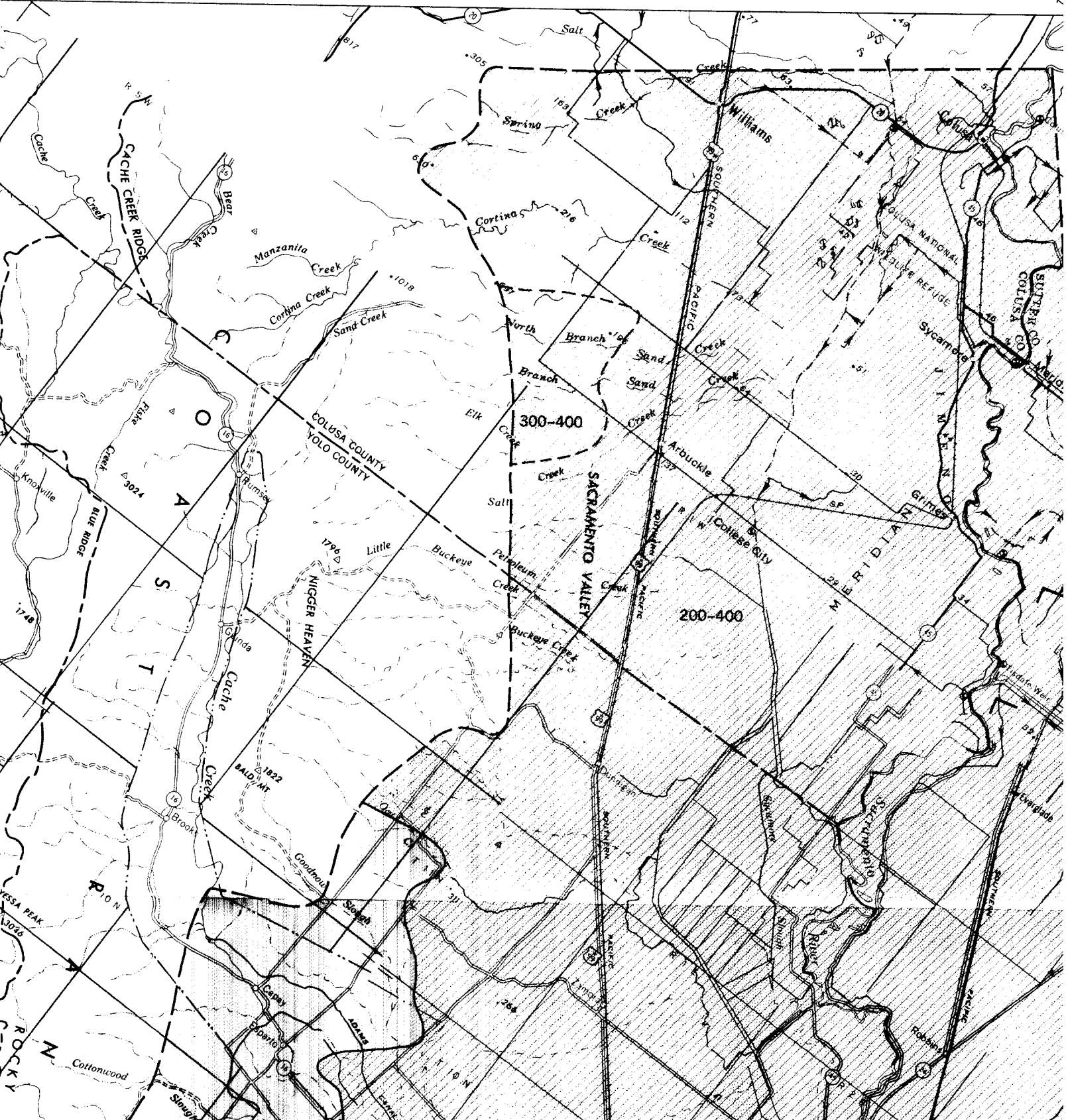


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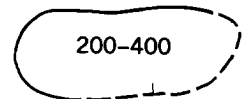
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EXPLANATION



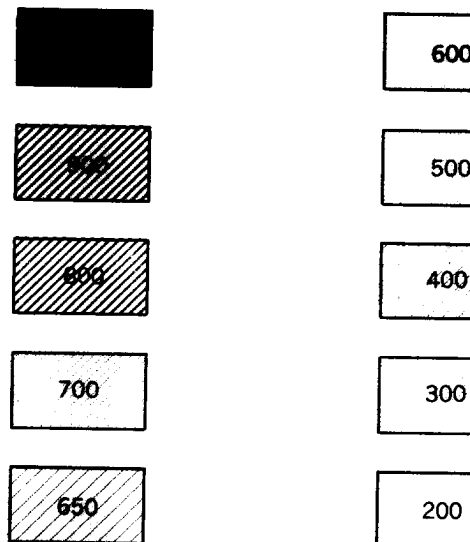
Radioactivity boundary

Solid where well defined, dashed where tran
Numbers indicate general range of radio
levels in counts per second



Single line traverses made in inaccessibl
Hachures point toward lower level of radioa

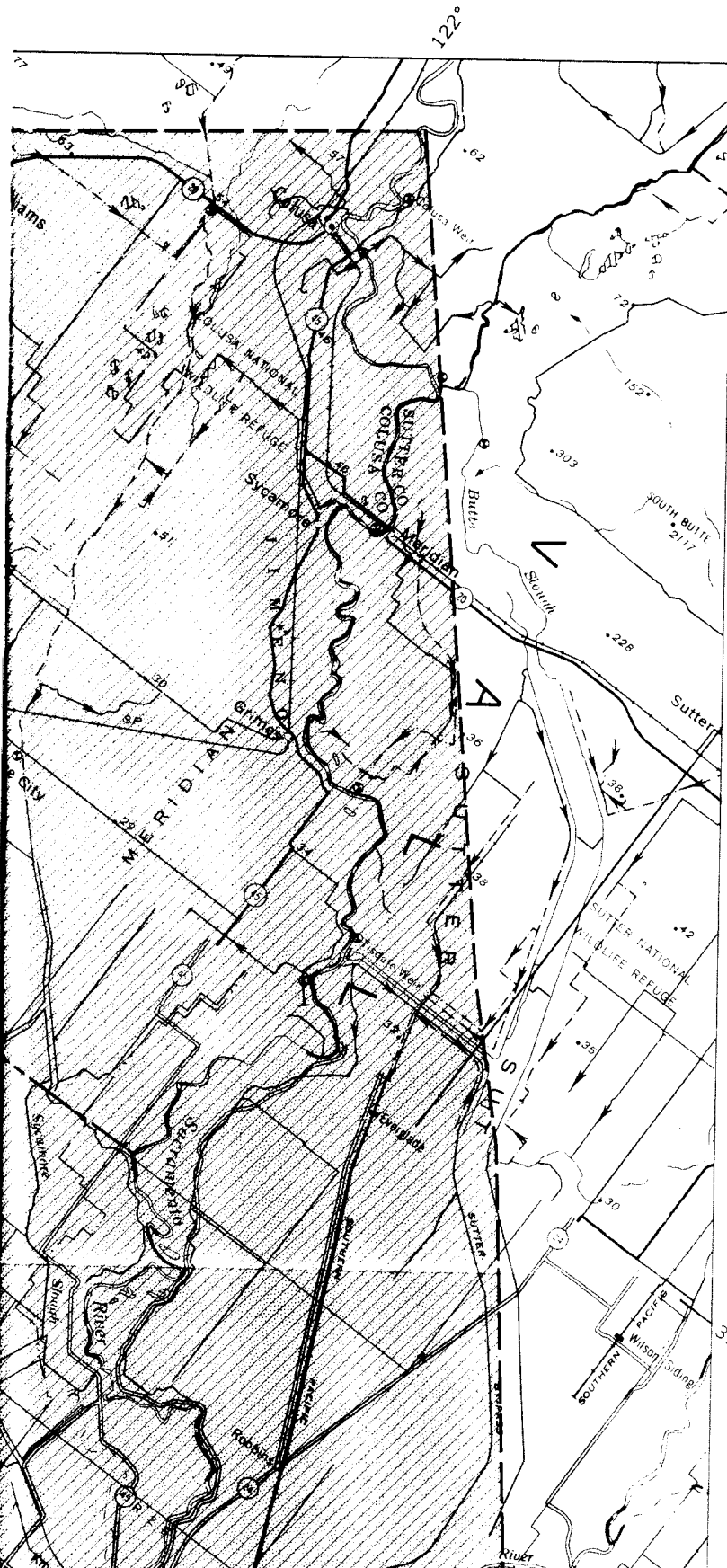
Boundary of area surveyed



Approximate upper level within area of si
radioactivity
Numbers indicate counts per second

EXPLANATORY TEXT

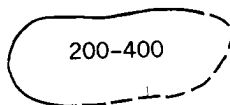
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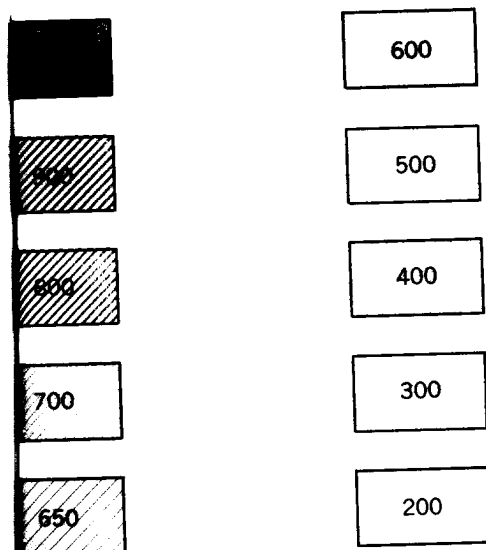
EXPLANATION



Radioactivity boundary
 where well defined, dashed where transitional.
 numbers indicate general range of radioactivity
 in counts per second

line traverses made in inaccessible areas
 arrows point toward lower level of radioactivity

Boundary of area surveyed



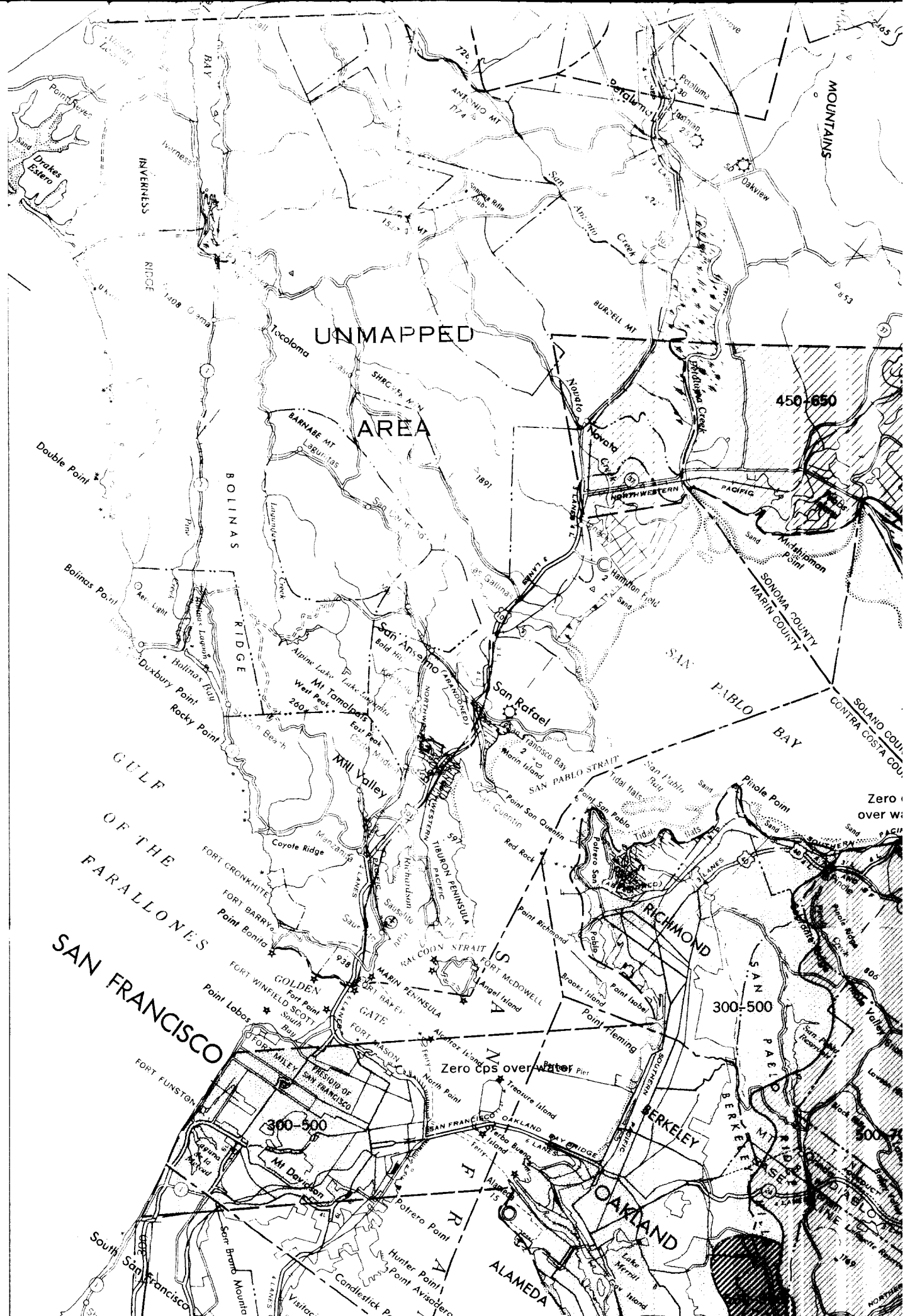
Approximate upper level within area of similar
 radioactivity
 Numbers indicate counts per second

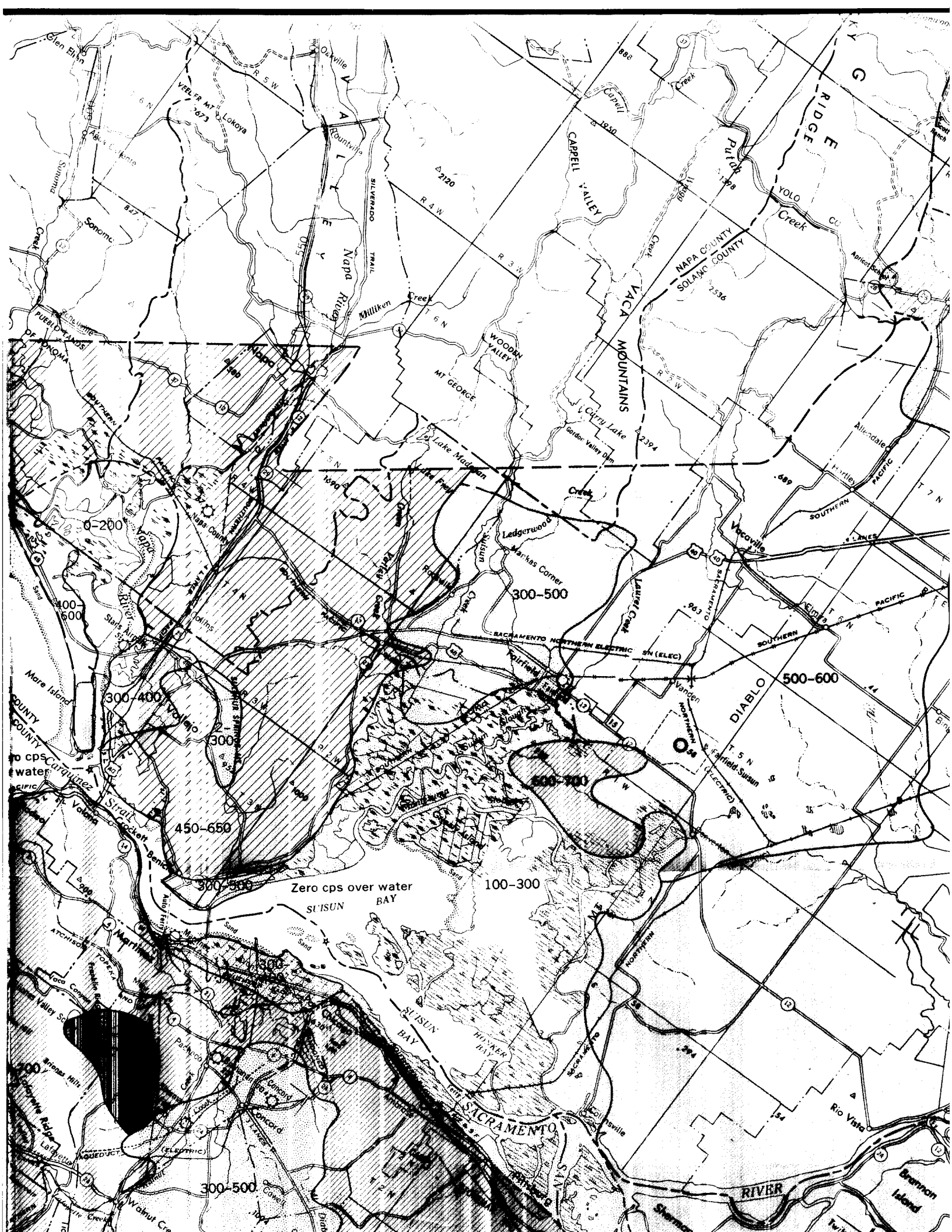
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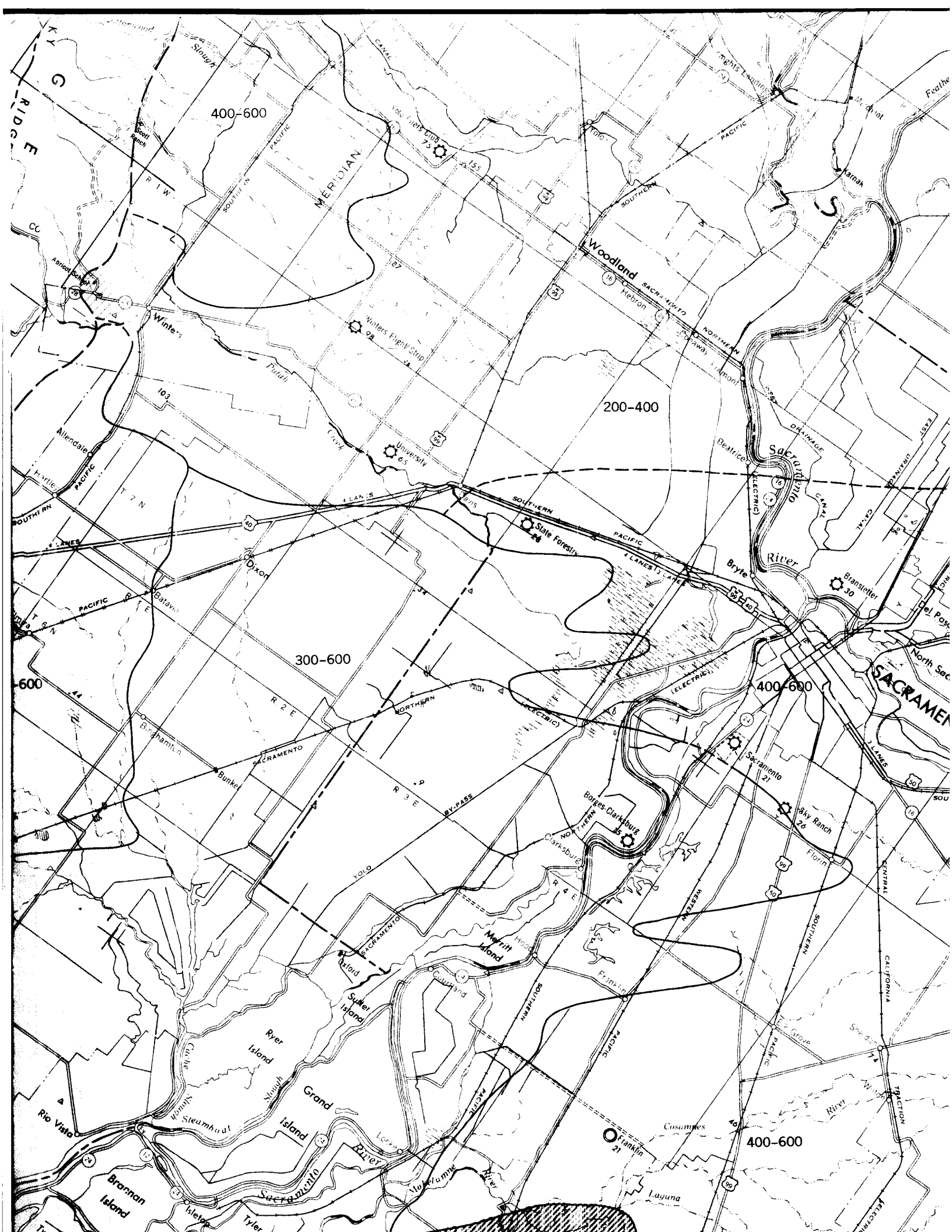
Survey was made with scintillation
 equipment (Davis and Reinhardt,

123°

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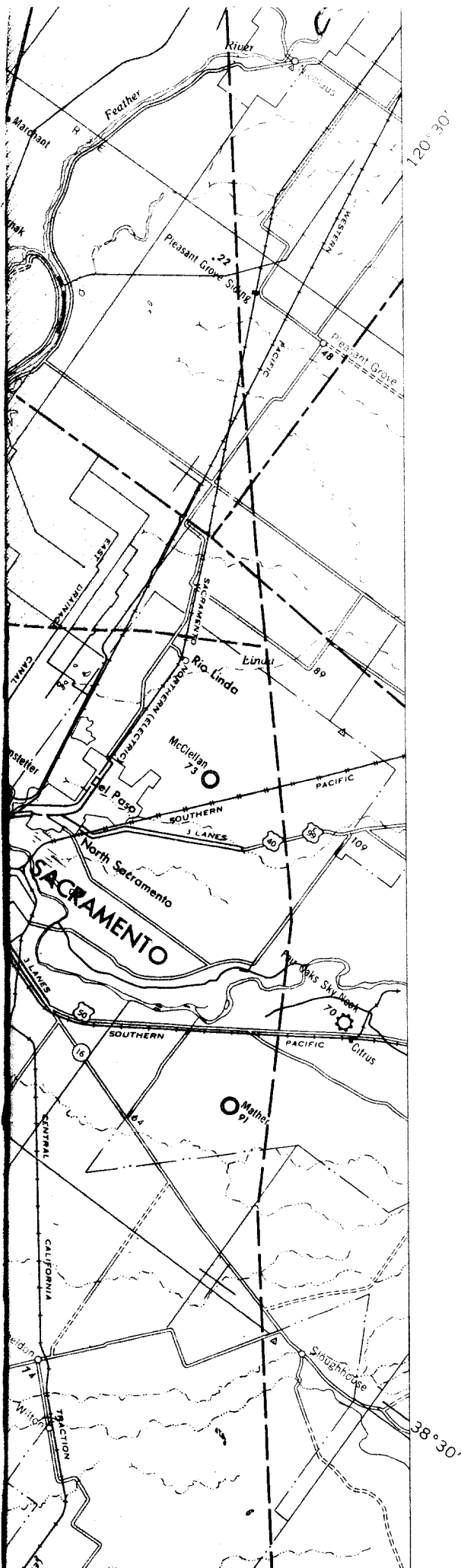
The survey was made with scintillation detection equipment (Davis and Reinhardt, 1957) installed in a twin-engine aircraft. Parallel northeast-southwest flight traverses spaced at one-mile intervals were flown at a nominal altitude of 500 feet above the ground. Single line traverses were flown along roads in areas where rough topography prevented systematic surveying. The flight path of the aircraft was recorded by a gyrostabilized continuous-strip-film camera. The radioactivity data were compensated for deviations from the 500-foot surveying altitude, and for the cosmic-ray component.

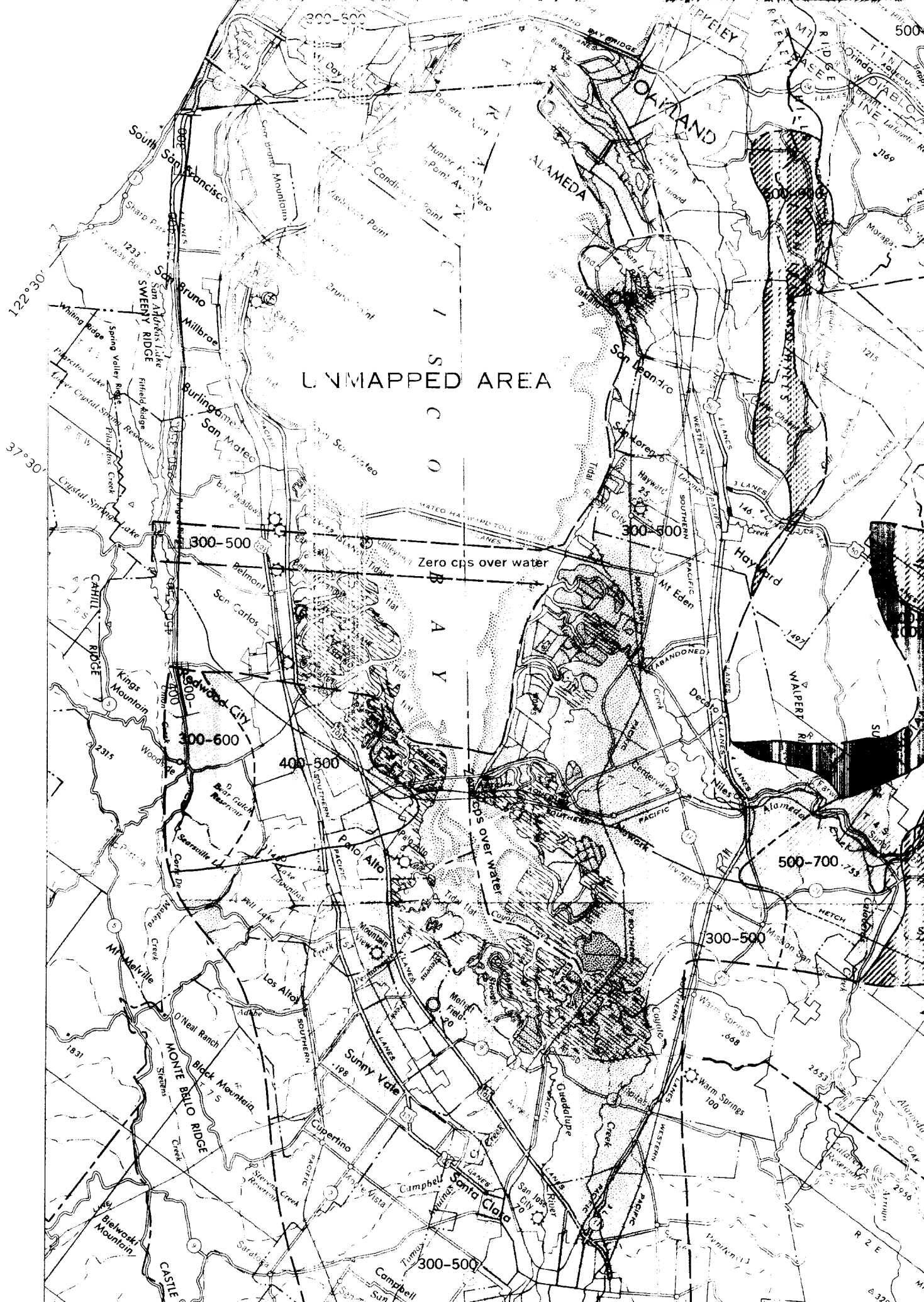
The effective area of response of the scintillation equipment at an altitude of 500 feet is about 1,000 feet in diameter, and the radioactivity recorded is an average of the radioactivity received from within that area. The scintillation equipment accepts only pulses originating from gamma radiation with incident energies greater than 50 kev (thousand electron volts). A cesium-137 source is used during periodic calibrations to assure uniformity of equipment response.

The gamma-ray flux at 500 feet above the ground has three principal sources: cosmic radiation, radionuclides in the air (mostly radon daughter products), and radionuclides in the surficial layer of the ground. The cosmic component is determined twice daily by calibrations at 2,000 feet above the ground, and is removed from the radioactivity data.

The component due to radionuclides in the air at 500 feet above the ground is difficult to evaluate. It is affected by meteorological conditions, and a tenfold change in radon concentration is not unusual under conditions of extreme temperature inversion. However, if inversion conditions are avoided, the air component may be considered to be fairly uniform on a given day in a particular area, and will not affect the discrimination of the radioactivity levels that reflect changes in the ground component.

The ground component comes from approximately the upper few inches of the ground. It consists of gamma rays from natural radionuclides, mostly members of the uranium and thorium radioactive decay series and potassium-40, and fallout of radioactive nuclear fission products. Locally the amount of fallout must be small, because the lowest total radiation



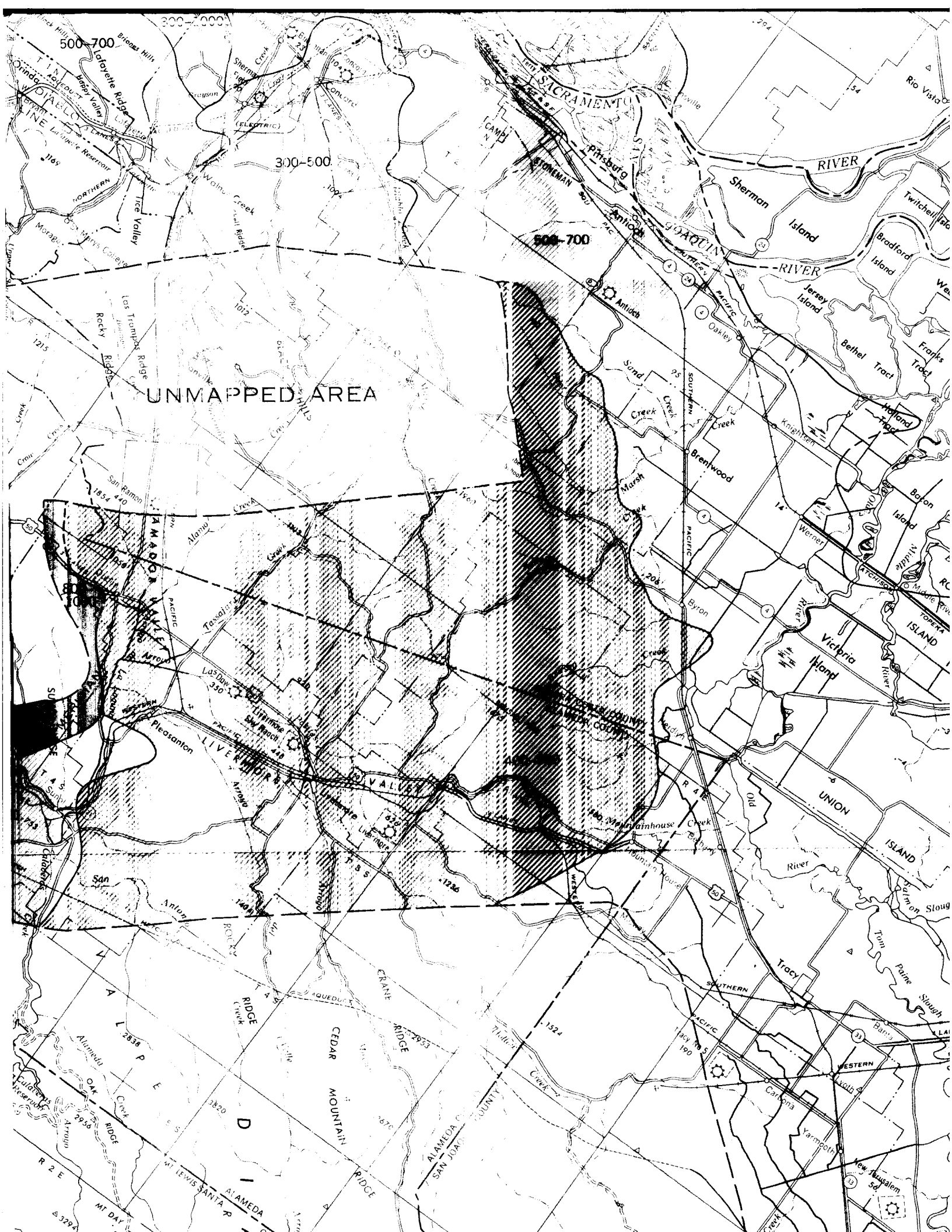


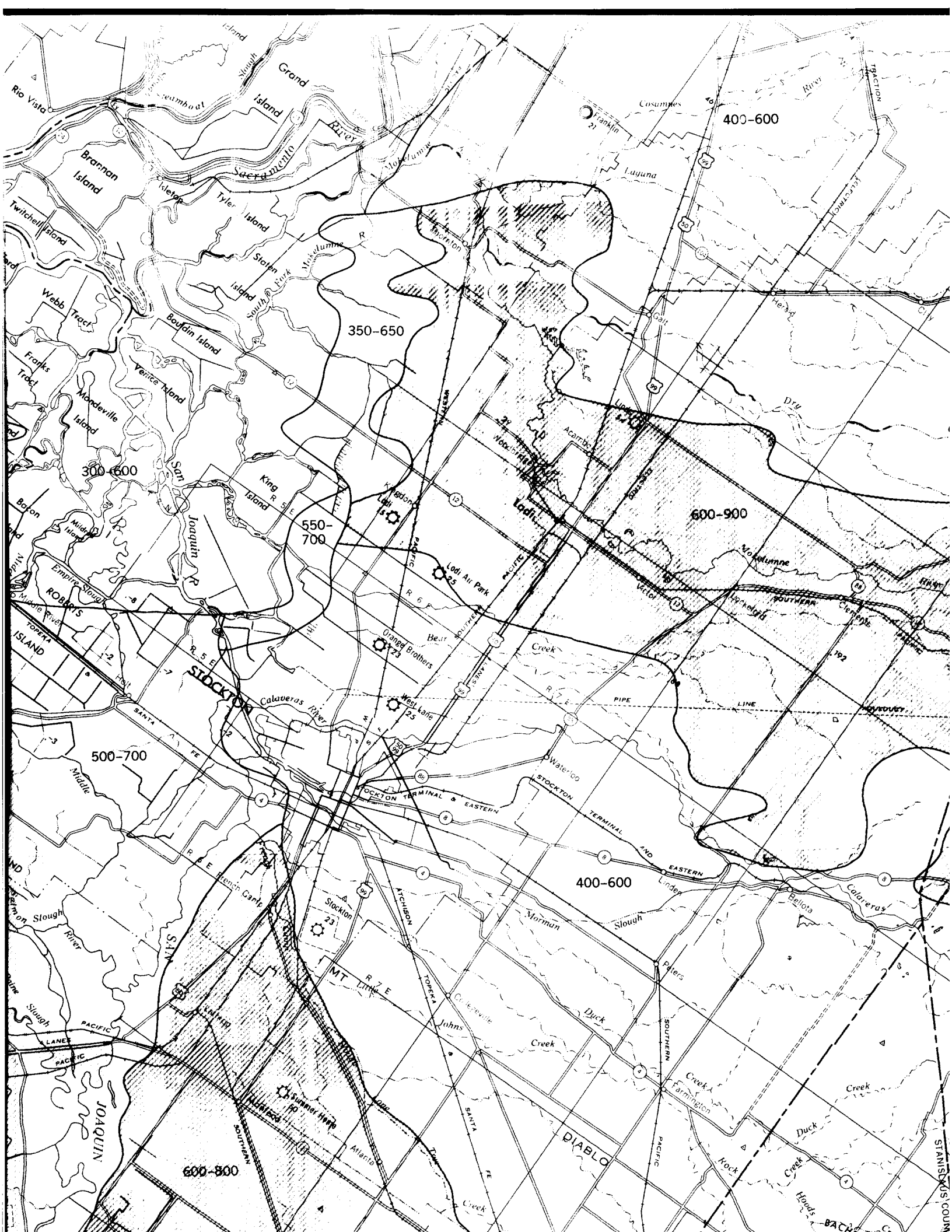
UNMAPPED AREA

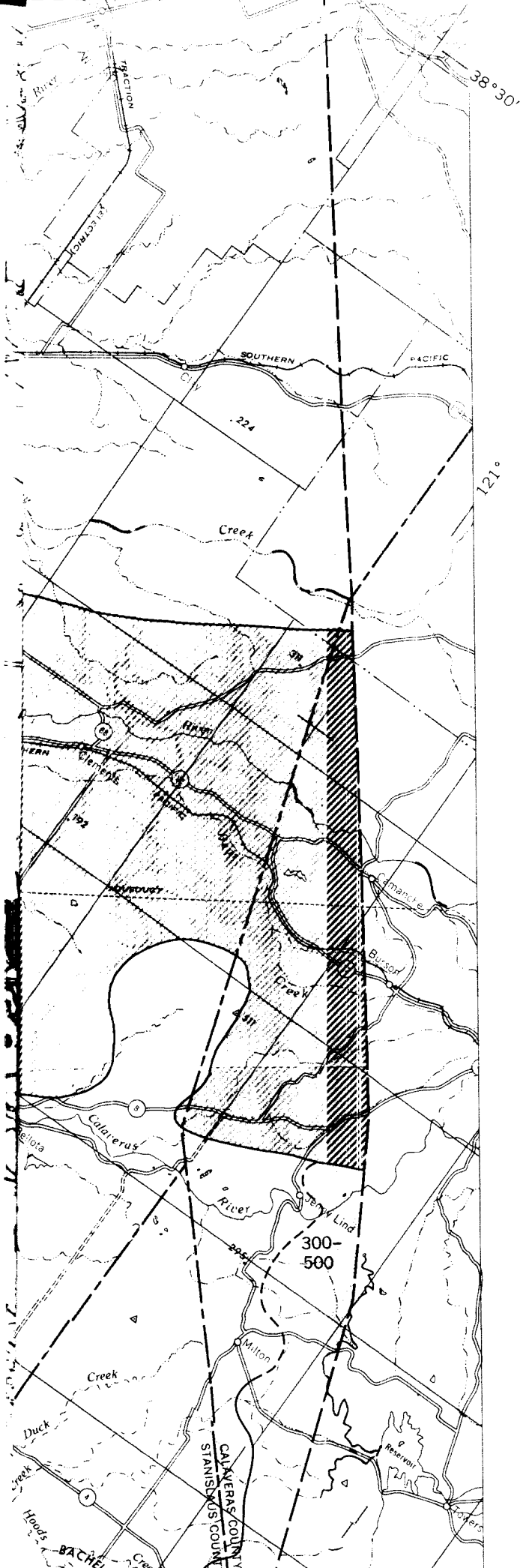
Zero cps over water

2 cps over water

300-500







The ground component comes from approximately the upper few inches of the ground. It consists of gamma rays from natural radionuclides, mostly members of the uranium and thorium radioactive decay series and potassium 40, and fallout of radioactive nuclear fission products. Locally the amount of fallout must be small, because the lowest total radiation measured is 150 cps (counts per second) in areas not affected by absorption of gamma rays by water. The distribution of fallout in the area surveyed is assumed to be uniform.

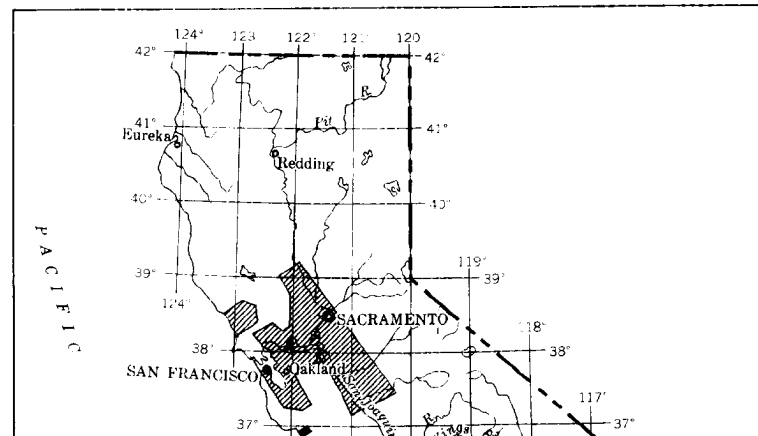
Range in natural radioactivity within the areas flown is moderate, from 0 to 200 cps north of San Pablo Bay to 800 to 1000 cps in the Mt. Diablo region.

In general, the aeroradioactivity is highest over igneous rocks or soils derived from igneous rocks and is lowest over marshy areas due to the masking effect of water. The greatest variation is in the Coast Range areas where the rocks are lithologically more complex.

A detailed study of the San Francisco aeroradioactivity survey is published separately (Books, in press).

Davis, F. J., and Reinhardt, P. W., 1951. Instrumentation in aircraft for radiation measurements: Nuclear Sci. and Eng., v. 2, no. p. 713-727

Books, K. G., in press, Aeroradioactivity survey and related surface geology of parts of the San Francisco region, California (ARMS-U. S. Atomic Energy Comm. Rept. CEX-58.



ground component comes from approximately the upper few inches of the ground. It consists of gamma rays from natural radioisotopes, mostly members of the uranium and thorium radioactive decay series and potassium-40 fallout of radioactive nuclear fission. Locally the amount of fallout must be low, because the lowest total radiation level is 150 cps (counts per second) in areas not affected by absorption of gamma rays in water. The distribution of fallout in the area surveyed is assumed to be uniform.

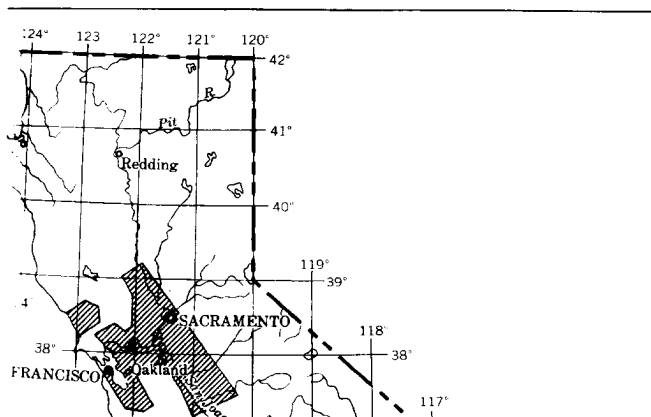
Level of natural radioactivity within the region is moderate, from 0 to 200 cps in San Pablo Bay to 800 to 1000 cps in the Diablo region.

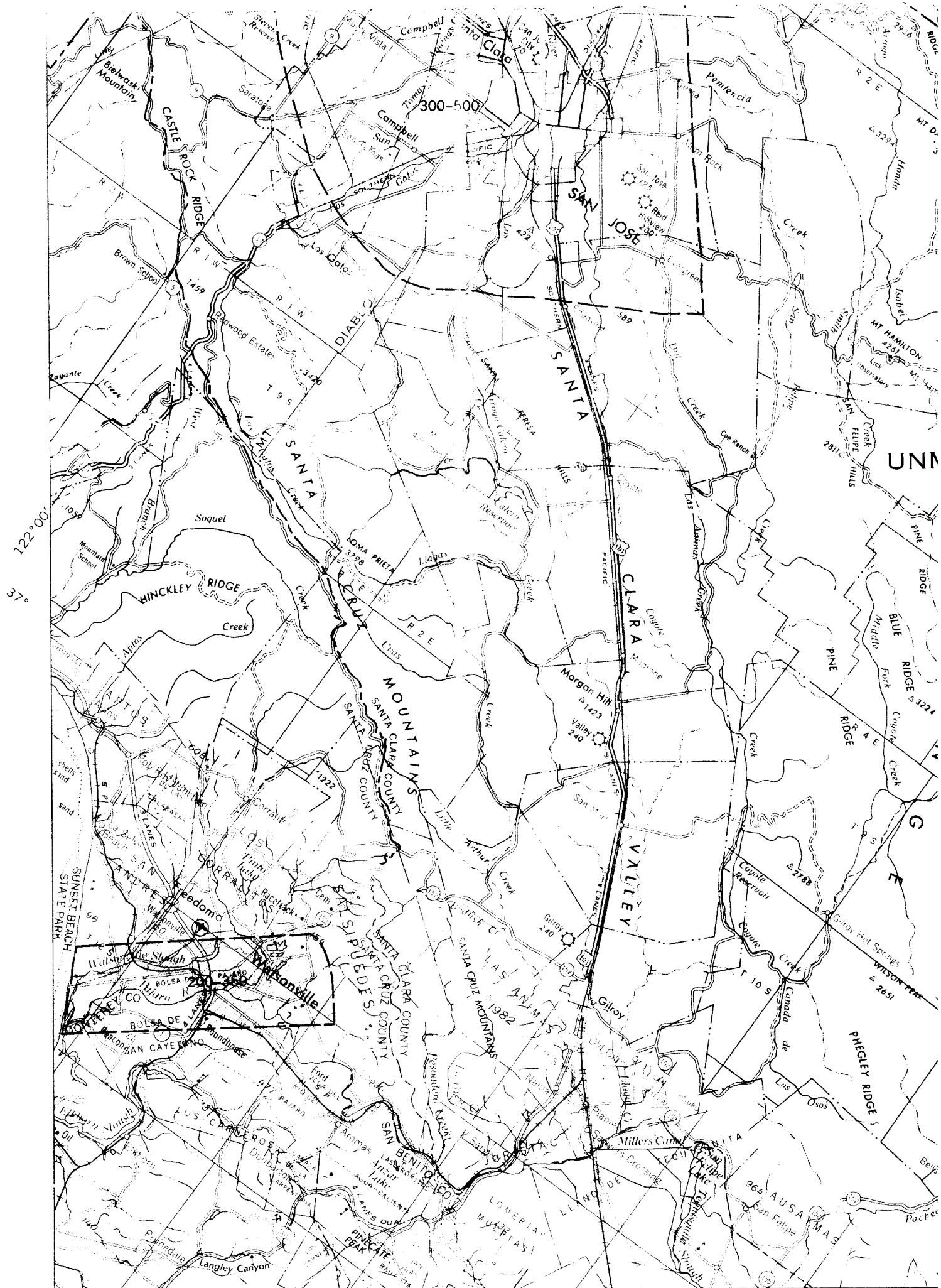
Generally, the aeroradioactivity is highest over igneous rocks or soils derived from igneous rocks and is lowest over marshy areas because of the masking effect of water. The greatest variation is in the Coast Range areas where geology is lithologically more complex.

Detailed study of the San Francisco aeroradioactivity survey is published separately (in press).

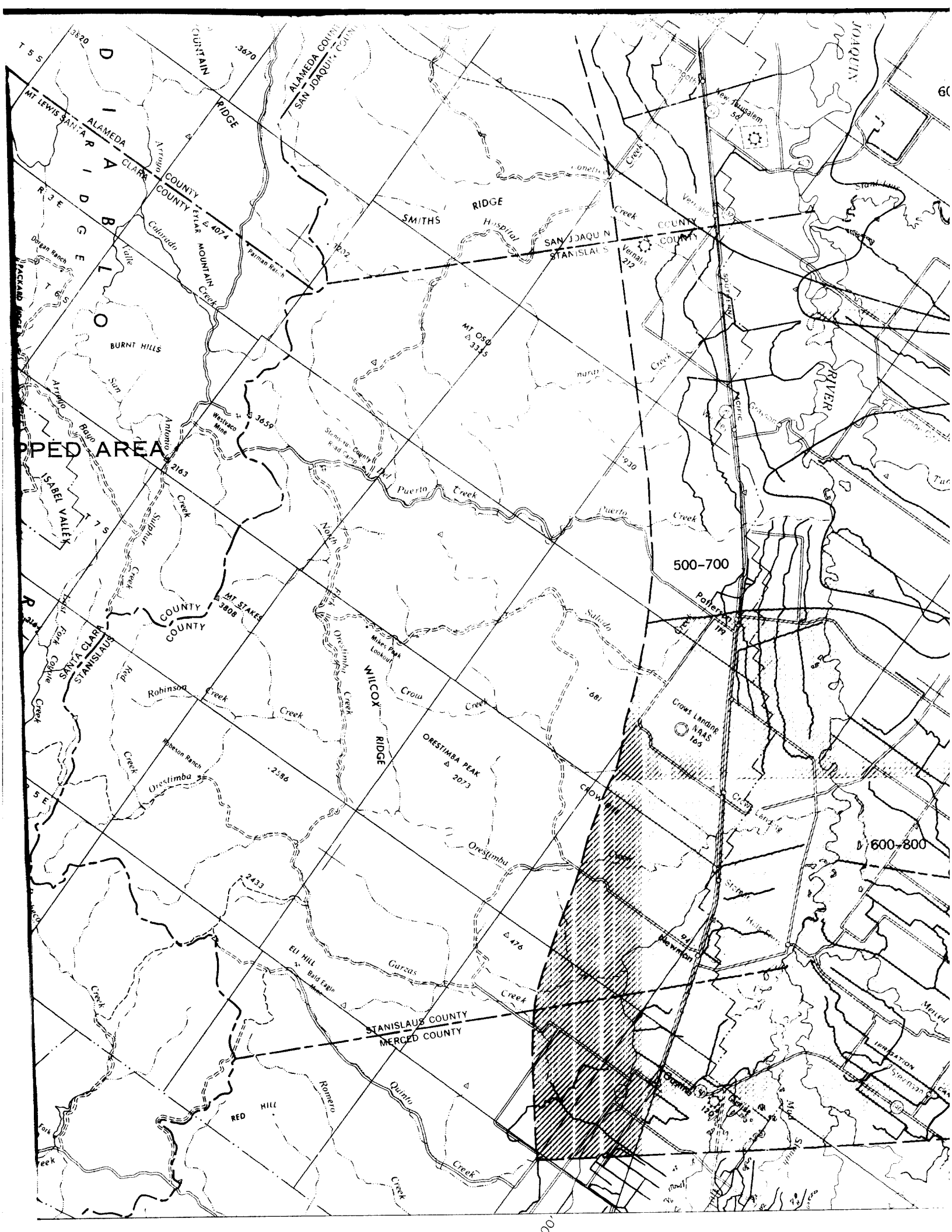
See, F. J., and Reinhardt, P. W., 1957, Aeroradioactivity in aircraft for radiation measurements: Nuclear Sci. and Eng., v. 2, no. 6, p. 727.

See, K. G., in press, Aeroradioactivity and related surface geology of parts of the San Francisco region, California (ARMS-I): Atomic Energy Comm. Rept. CEX-58.4.5

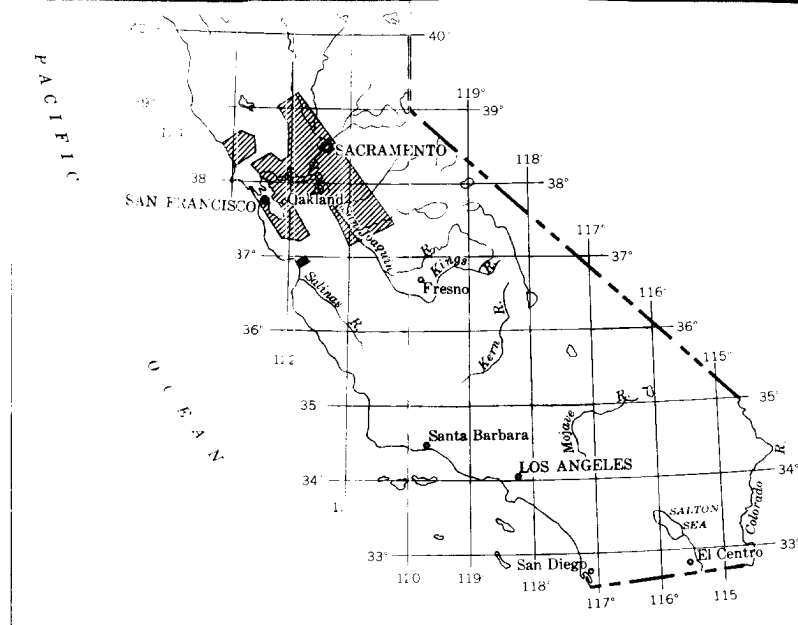
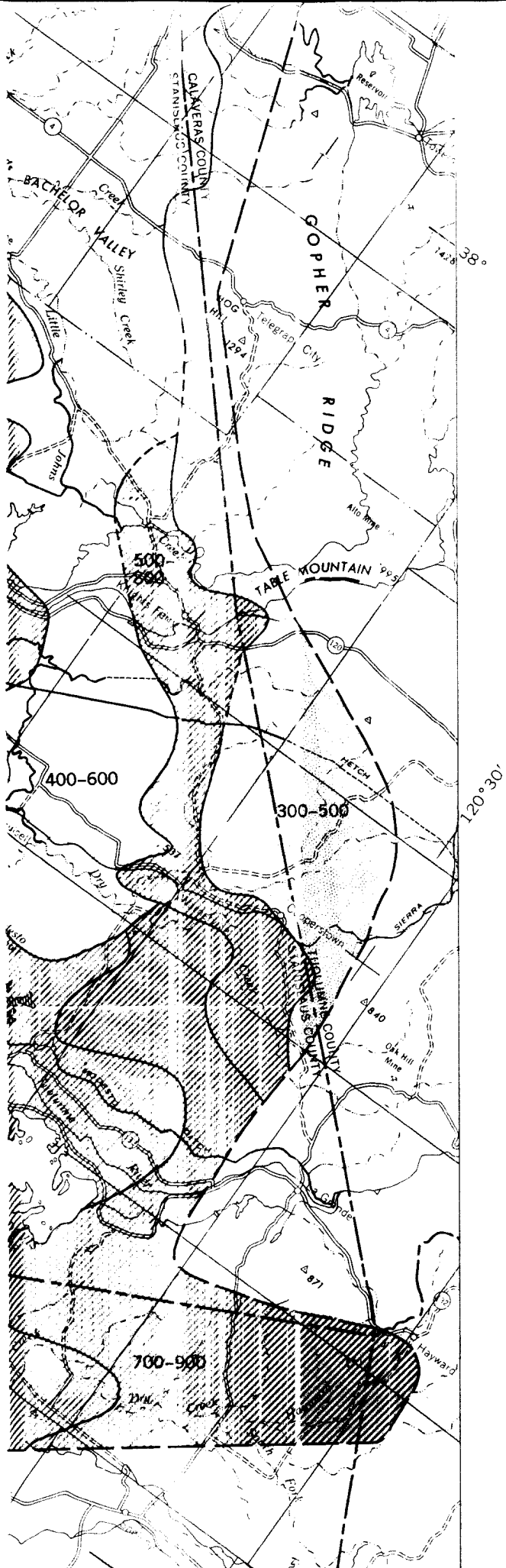




Base from Army Map Service 1:250,000 series:

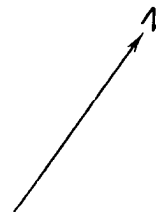




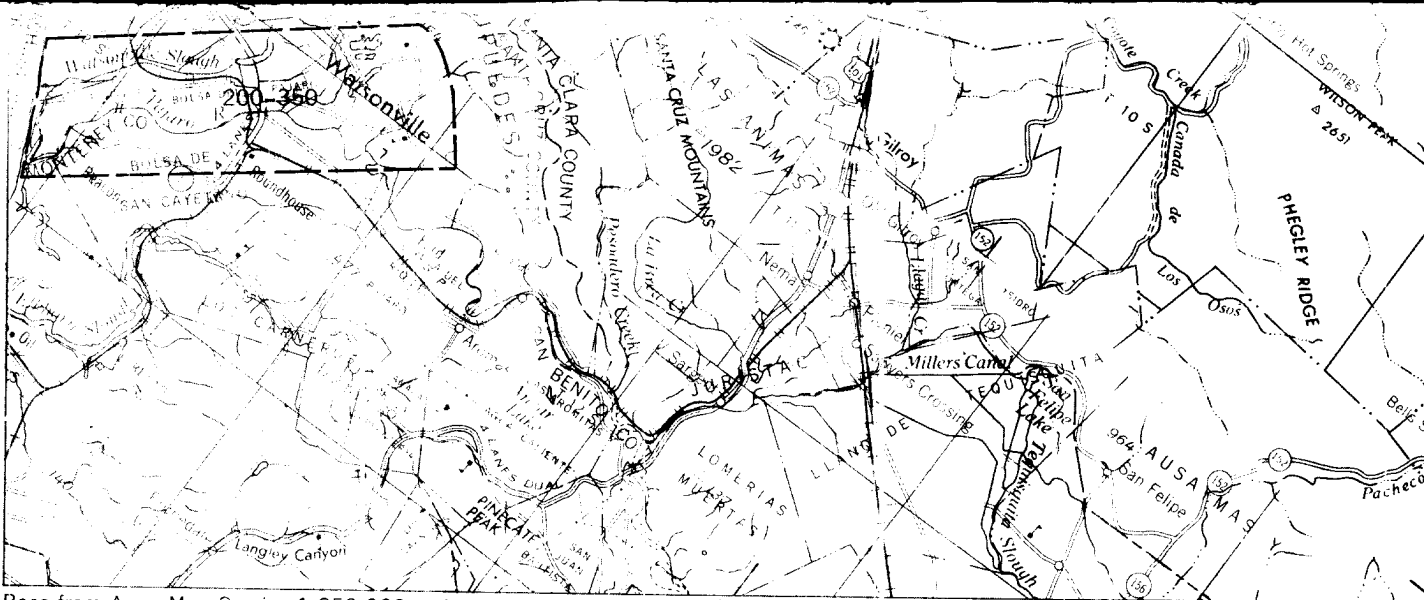


0 50 100 150 200 MILES

INDEX MAP OF CALIFORNIA SHOWING
AREAS SURVEYED FOR THIS REPORT



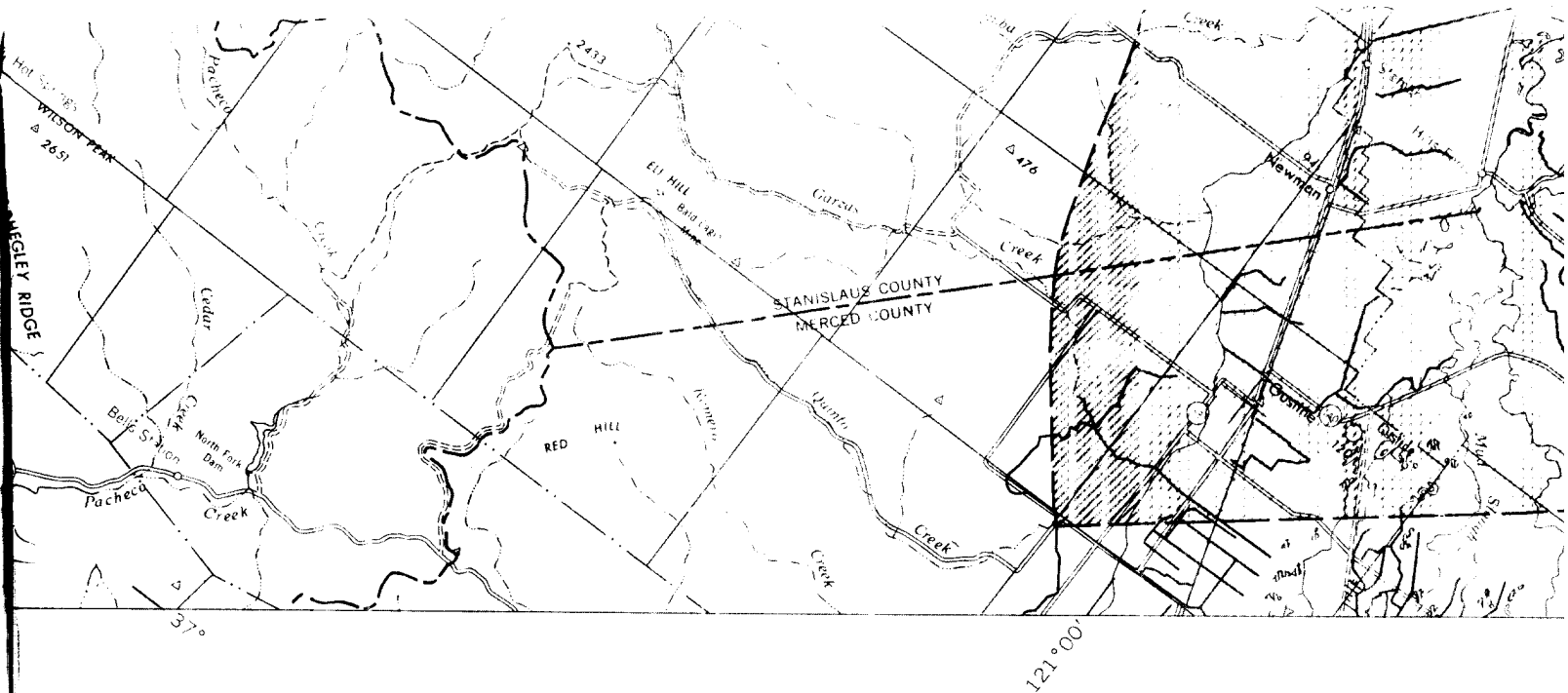
1963 MAGNETIC DECLINATION VARIES BETWEEN
17°00' AND 18°00' E.



Base from Army Map Service 1:250,000 series:
 Chico, 1958; Sacramento, 1945; San Francisco, 1956;
 San Jose, 1945; Santa Rosa, 1944; and Ukiah, 1957

PLATE 1.—NATURAL GAMMA AE

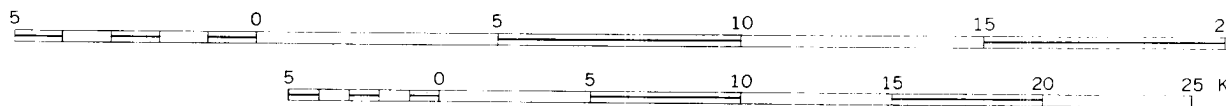
AEC-CEX 58.4.5
 GEOPHYSICAL INVESTIGATIONS
 MAP GP-483



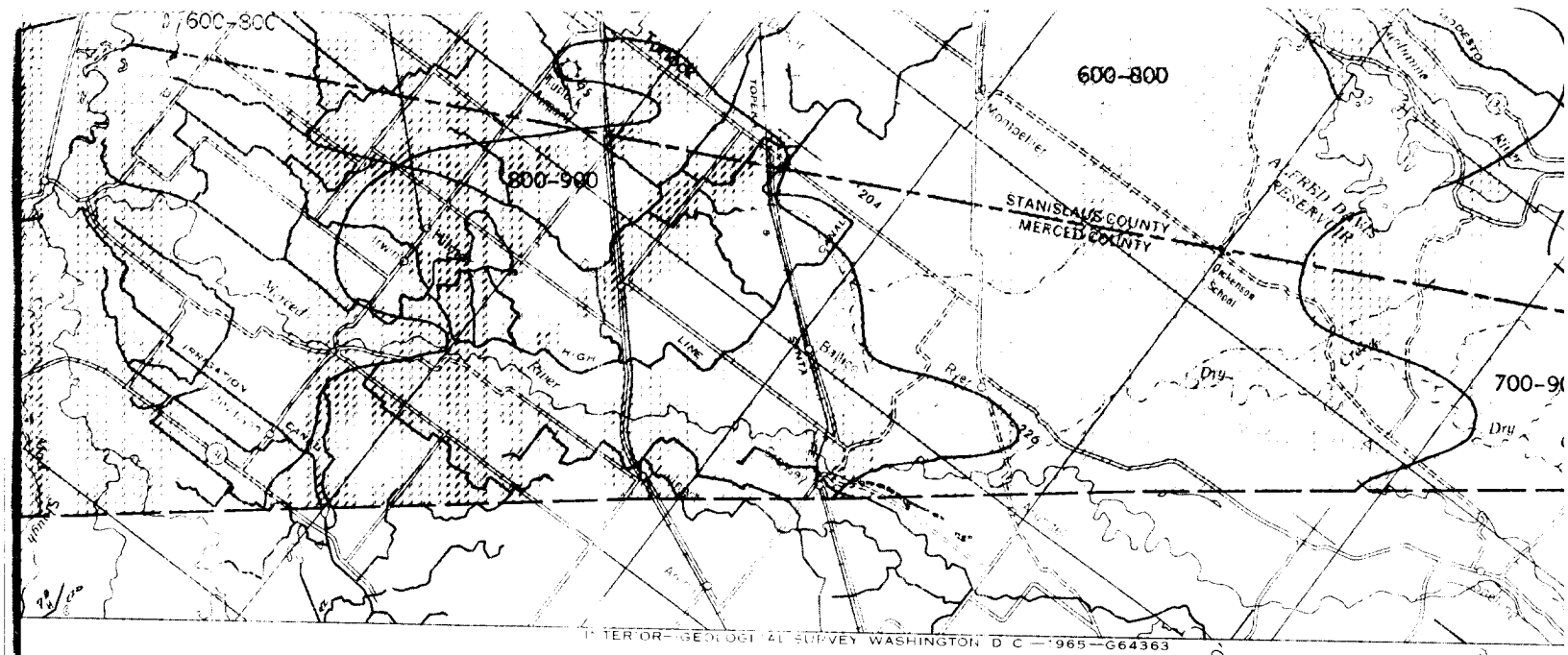
AERORADIOACTIVITY MAP OF PARTS OF T

By
Kenneth G. Books

SCALE 1:250 000



1965



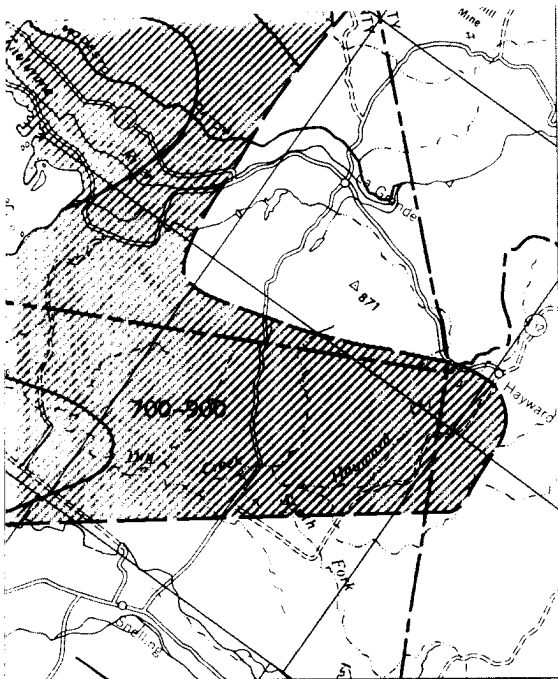
INTERIOR GEOLOGICAL SURVEY WASHINGTON D C 965-664363

Aeroradioact
the ground u
J. L. Meusch

OF THE SAN FRANCISCO REGION, CALIFORNIA

20 25 MILES
25 KILOMETERS

ELEVATION VARIES BETWEEN
17°00' AND 18°00' E.



37°30'
Aeroradioactivity survey made at 500 feet above
the ground under the direction of J. A. Pitkin,
J. L. Meuschke, and G. E. Andreasen

CALIFORNIA

For sale by U.S. Geological Survey, price 75 cents
Map obtainable from U.S. Geological Survey, Washington, D. C. 20242